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Map Design: An On-the-Road Evaluation of the Time to Read Electronic Navigation Displays

Christopher Nowakowski and Paul Green

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HUMAN FACTORS

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16. Abstract

This report covers the third of four experiments examining the time to read electronic maps while driving. Three factors were varied: (1) the number of streets displayed (12 street and 24 street maps), (2) the street label text size (10, 12, and 14 point), and (3) the time of day (day vs. night driving). Sixteen drivers (ages 18-30 and >65, both men and women) drove a test vehicle on public roads. Subjects were given three tasks while driving: (1) find the name of the street being driven, (2) find the name of a cross street ahead, and (3) find the location of a particular street on the map.

The largest effect was age which increased task response times by 40 to 80%. Each additional labeled street increased the response time by 7 to 140 ms depending on the task (up to 30%). Using 14 point reduced response time by 200 ms (up to 10%).

Subjective ratings by the drivers revealed uneasiness about their ability to drive safely when the task required more than 5 seconds to complete. To avoid this discomfort, using 14 point text and no more than 12 labeled streets is recommended.

Further, average response times from on-the-road were within 15% of the mean for the same task in a previous simulator experiment. The pattern of results (factors significant, their relative impact) were also similar, validating the simulator results.

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Map Design: An On-the-Road Evaluation of the Factors Affecting the Time to Read Electronic Maps

UMTRI HUMAN FACTORS

UMTRI Technical Report 98-4
Christopher Nowakowski and Paul Green

University of Michigan
Ann Arbor, Michigan, USA

1 ISSUES

On-the-Road Evaluation

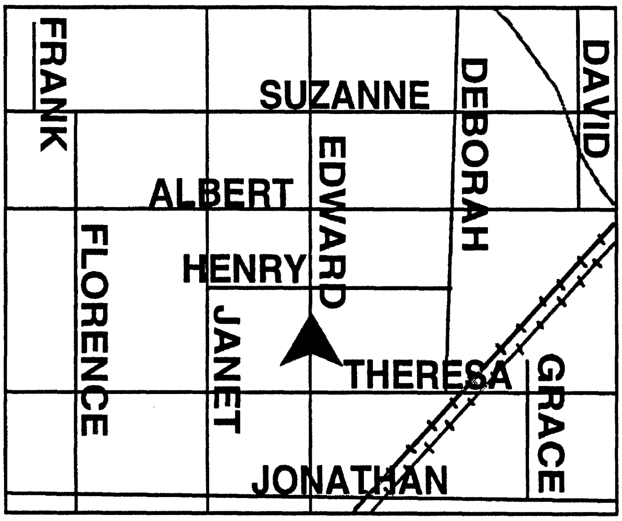
1. When do drivers feel that map reading is unsafe while driving?
2. How many streets should be displayed on an in-vehicle navigation system?
3. What size text should be used for the street labels?
4. What is the effect of time of day (day vs. night) on map reading?

Simulator Validation

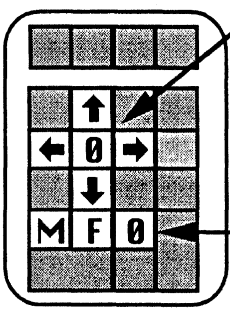
1. How do the previous simulator results compare with the on-the-road results?

2 MAP TASKS

Sample Map



Response Keypad



Task 3 Directional Keys

↑ ahead → right
↓ behind ← left
0 not there

Tasks 1 and 2 Response Keys

M male 0 not there
F female

Task 1 - On Street

What street are you on?
Subject Finds: Edward
Subject Responds: male (M key)

Task 2 - Cross Street

What is the 3rd Cross Street?
Subject Finds: Suzanne
Responds: female (F key)

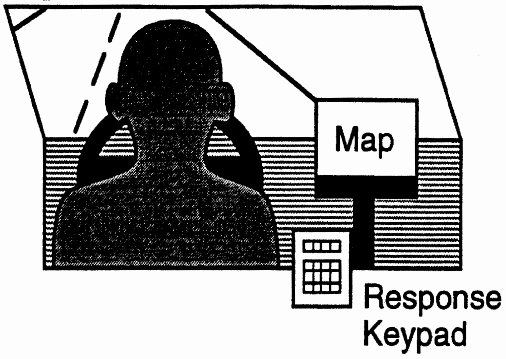
What is the 4th Cross Street?
Subject Finds: only 3 streets
Responds: not there (0 key)

Task 3 - Where is?

Where is Jonathan?
Response: behind (↓)
Where is Florence?
Response: left (←)
Where is David?
Response: right (→)
Where is Albert?
Response: ahead (↑)
Where is Tammy?
Response: not there (0)

3 METHOD

Expressway Driving Scenario



Subjects

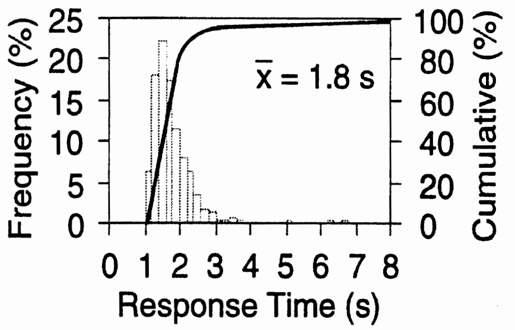
Session		Age 18 - 30		Age >65	
1	2	Men	Women	Men	Women
Day	Night	2	2	2	2
Night	Day	2	2	2	2

Main Test Conditons

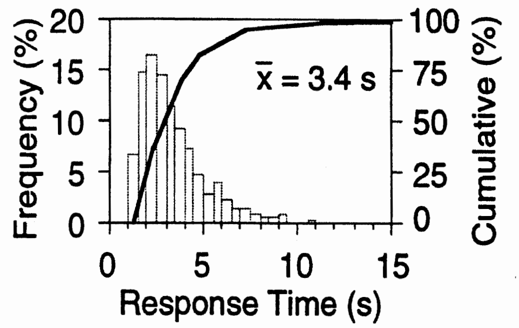
Text Size	12 Streets	24 Streets
10 POINT	√	√
12 POINT	√	√
14 POINT	√	√

4 ON-THE-ROAD EVALUATION RESULTS

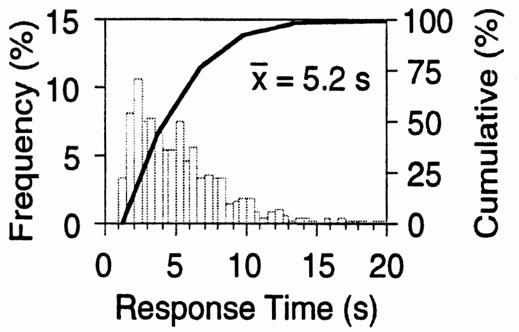
Task 1 - On Street



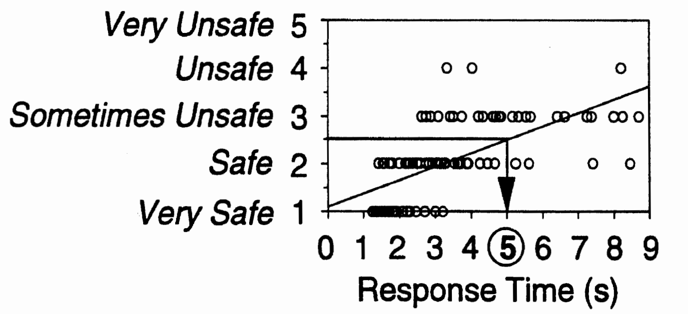
Task 2 - Cross Street



Task 3 - Where is?

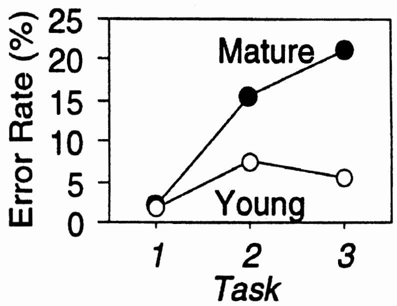


Issue 1 - When is map reading unsafe?

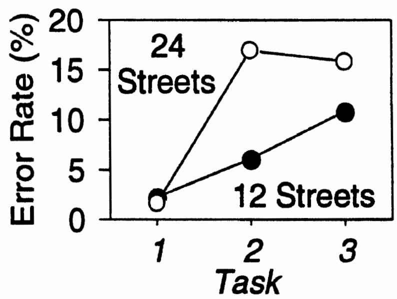


Error Rates

1. Age Effect

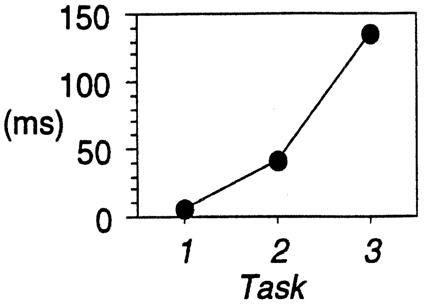


2. Number of Streets Effect



Issue 2 - How many streets to display?

Response time increase per each displayed street



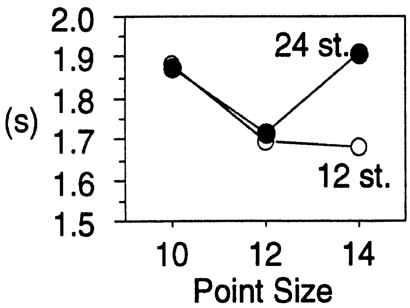
Task 3 Streets Effect

Recommendation:

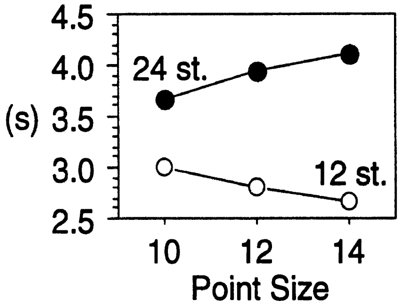
Display ≤12 Streets

Issue 3 - What text size to use?

Task 1 Point Size Effect



Task 2 Point Size Effect



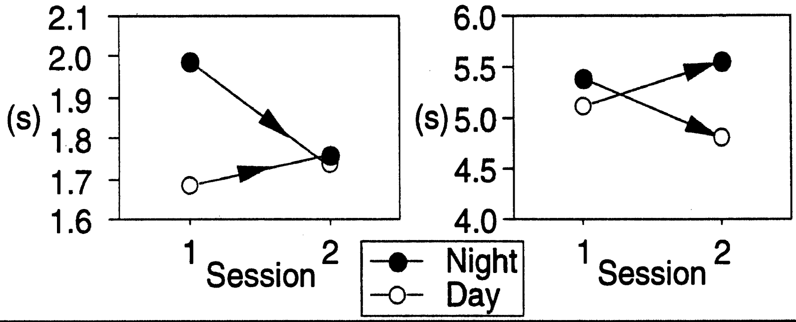
Recommendations:

1. When possible, **Use 14 point.**
2. Do **not** use <12 point

Issue 4 - Day/Night Effects

Task 1 - Night learning is more difficult

Task 3 - Night increases response time



Recommendation:

Issues of color, luminance, and contrast for night-use maps need to be addressed in further reasearch.

Response Time Regression Equations (ms)

Task 1 - On Street

$$RT = 6710 + 325*(A) + 6.67*(S) + 33.75*(P)^2 - 832.50*(P) + 9.58*(C)$$

Task 2 - Cross Street

$$RT = 1210 + 575*(A) + 370*(X) + 40.83*(S) + 8.08*(P-12)*(SL) + 40.83*(S-12)*[MINIMUM(1,X-2)]$$

Task 3 - Where is?

$$RT = [1630 + 1235*(A) + 380*(T) + 136*(S) + 27*(A)*(SL) + 475*(L)]*(SR)$$

Regression Equations Terms

A = Age { -1 if young; +1 if mature }

T = Time of day { -1 for day; +1 for night }

S = Number of streets (S ≥ 1)

X = Target cross street (X ≥ 1)

P = Point size (10 ≤ P ≤14)

L = Target location { -1 if ahead; 0 if not there; +1 if behind, left or right }

C = Clutter { 0 if ≤ 12 point; (P-12)(S-12.52) if > 12 pt. }

SL = Street level { -1*(24-S) if S ≤ 12; +1*(S-12) if S > 12 }

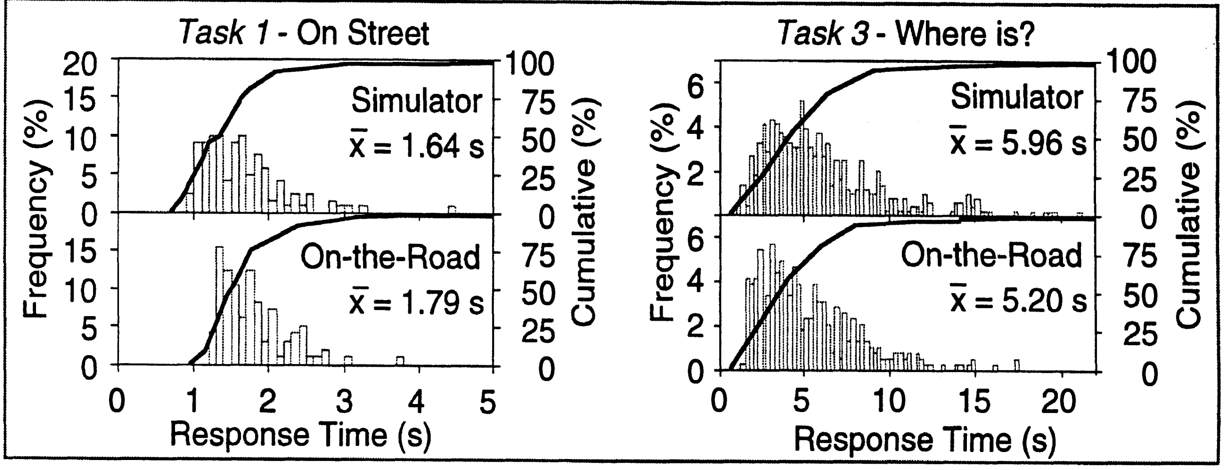
SR = Search result { 1 if found; 1.70 if not found }

5 SIMULATOR VALIDATION RESULTS

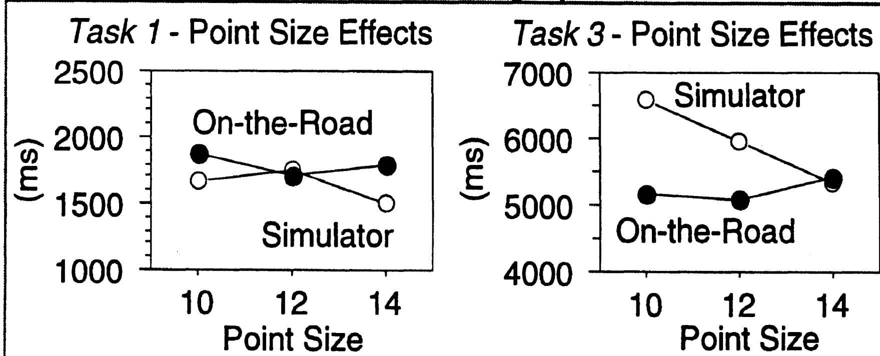
Subjects

Experiment	Age 18 - 30		Age 65<		Trials per Subject	
	Men	Women	Men	Women	*Task 1*	*Task 3*
Simulator	**5**	**5**	**5**	**5**	**6**	**24**
On-the-Road	**4**	**4**	**4**	**4**	**24**	**48**

Response Time Comparison



Differences in Experimental Findings



Conclusions:
The optimal point size was also dependent upon the display resolution and location (character visual angle).

PREFACE

This research was funded by the University of Michigan Intelligent Transportation Systems (ITS) Research Center for Excellence, formerly the IVHS Research Center for Excellence. The program is a consortium of companies and government agencies, working with the University, whose goal is to advance ITS research and implementation.

The current sponsors are:

- Ann Arbor Transit Authority
- Automobile Association of America (AAA)
- Chrysler Corporation
- Federal Highway Administration (FHWA)
- Ford Motor Company
- General Motors Corporation
- Hewlett Packard
- Michigan Department of Transportation
- Nissan Motors
- NOVA Laboratories
- Orbital Sciences
- Road Commission of Oakland County
- Ryder Trucks
- Siemens Automotive
- Toyota Motor Corporation

We would like to thank the lead corporate sponsor for this project, Toyota Motor Corporation, for their support. Originally Cale Hodder, and now Jim Bauer (both from Toyota), have served as project technical monitors.

Electronic maps are commonplace in automotive navigation systems in Japan, and soon will be common in the U.S. and Europe. To make such maps safe and easy to use while driving, it is important to know how engineering, individual, and task factors affect reading time, and how reading time can be minimized. The more time drivers spend looking in the vehicle, the less time they spend looking at the road, increasing the opportunity for crashes. Given the almost complete absence of literature on the time to read maps prior to this project, two specific issues were addressed.

Issue 1: How long does it take to read an electronic local map as a function of label size and orientation, the number of streets shown, the percentage of streets labeled, display location, and the driver's task?

Issue 2: When do drivers desire area maps instead of turn (intersection) displays?

These issues were examined in 5 reports summarized on the next page:

Green, P. (1998). Reading Electronic Area Maps: An Annotated Bibliography, (Technical Report UMTRI-98-38).

> This report contains a collection of abstracts generated by the author. Primary articles concerned performance differences in reading street names due to font, how people follow directions using street maps, etc. There were no articles in the literature that methodically considered how factors related to street map design affect task completion time. Secondary articles considered color coding, symbols for tourist information, etc.

Authors to be determined (1998). Preliminary Examinations of the Time to Read Electronic Maps: The Effects of Text and Graphic Characteristics, (Technical Report UMTRI-98-36).

> This report summarizes the initial series of simulator experiments concerning reading electronic maps. Included were efforts to identify representative maps and street names for testing and a pilot experiment concerning the subjective legibility of various map typefaces. In the main experiment, the time to read the electronic maps was found as a function of text size, the number of streets, text orientation, and grid-likeness.

Brooks, A. and Green, P. (1998). Map Design: A Simulator Evaluation of the Factors Affecting the Time to Read Electronic Navigation Displays, (Technical Report UMTRI-98-7).

> This report describes a simulator experiment that was an extension of the first main experiment. This extension examined situations when only some of the street names were labeled, small text sizes, and the effect of map location in the vehicle.

Nowakowski, C. and Green, P. (1998). Map Design: An On-the-Road Evaluation of the Time to Read Electronic Navigation Displays, (Technical Report UMTRI-98-4).

> This report summarizes an on-the-road study that was run in parallel with the previous report and examined similar factors. The same text sizes and number of streets were used, but all the streets were labeled and the effect of day and night was studied. These results were used to bridge the laboratory results to real, on-the-road situations.

Brooks, A., Nowakowski, C., and Green, P. (1998). Turn-by-Turn Displays versus Electronic Maps: An On-the-Road Comparison of Driver Glance Behavior, (Technical Report UMTRI-98-37).

> This report describes an on-the-road study that examined when and how often drivers look at turn-by-turn and electronic map displays in route guidance. Factors examined included road type (residential, freeway, etc.) and the distance to the next turn/decision point.

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INTRODUCTION

Overview

Recently there has been an influx of in-vehicle navigation systems into the United States, both as standard equipment (on the Acura RL and several Lexus vehicles) and as aftermarket products such as the Rockwell (now Magellan) PathMaster, the Alpine voice navigation system, and the Philips (now VDO) Carin system. A major concern is that the in-vehicle maps provided by navigation systems may be difficult to read, distracting drivers from attending to the road ahead. Such distractions could provide increased opportunities for crashes (Green, 1997) as is suspected for cellular phones (Goodman, Bents, Tijerina, Wierwille, Lerner, and Benel, 1997).

In recognition of this safety concern, Paul Green is developing a Society of Automotive Engineers (SAE) standard, a precursor to an International Standards Organization (ISO) standard, on what drivers should be permitted to do with a navigation system while a vehicle is in motion. Of considerable value in developing such a standard would be baseline data on how long it takes to read a map as a function of its content and the task to be completed. Accordingly, this project is a timely coincidence.

There have been numerous studies concerning matters relating to human factors and the design of navigation displays. (See Green, 1992 for a review.) Almost all of the prior research has considered issues relating to the modality to be used for navigation information and attentional demands of particular implementations (Dingus, McGehee, Hulse, Jahns, Manakkal, Mollenhauer, and Fleischman, 1995; Green, Hoekstra, and Williams, 1993; Green, Williams, Hoekstra, George, and Wen, 1993), not the impact of specific map characteristics such as is addressed by this series of experiments. Therefore, this project breaks new ground.

The first report of this project was an annotated bibliography of the research on reading electronic area maps (Green, 1998). The report verified the a priori notion that relevant literature was limited. The vast majority of studies concern how colors should be assigned to areas on a map (states or provinces) so no two adjacent areas have the same color.

Several significant pilot studies were conducted as part of the first experiment. Those studies identified typical content of electronic maps (number of streets, street name length, etc. for the United States) and developed a task set representative of what drivers do. The first major laboratory experiment, conducted in a driving simulator, examined the time to read electronic maps as a function of numerous map display factors (Green, 1998). A total of 20 drivers (10 under 30 years of age and 10 over 65 years of age) operated a driving simulator while performing one of three tasks: (1) identifying the street being driven, (2) identifying a particular cross street, or (3) locating a particular street on a map. These same three representative tasks have been used consistently in this project. Further, they are interesting experimentally as they vary in complexity and completion time.

Variables examined in the first experiment included: (1) the number of streets shown (6 through 36), (2) label point size (12 and 18 point), (3) the street configuration (grid verses nongrid), and (4) the street label orientation (horizontal, vertical, and vertical stacked).

The results were that the response times increased as the number of streets shown increased. For the label size, the reading time for 18 point text was significantly slower (by 11 percent) than for 12 point, especially with a large number of streets on the map. Large point sizes combined with many visible streets created a cluttered map which dramatically increased the drivers' response times. Additionally, drivers were able to read the maps faster when the maps were based on a grid layout, rather than a less structured, more random arrangement. The regularity of the grid facilitated search. Finally, the best label orientations were horizontal for horizontal streets and vertical for vertical streets, even though horizontal text is normally easier to read. In this case, the vertical text facilitated the association of each label with a particular line representing a street.

Following the initial laboratory experiment, a second laboratory experiment was conducted in parallel with this on-the-road study to reexamine some of the map display factors (Brooks and Green, 1998). Using the same three tasks as the first experiment, the variables examined in the second experiment included: (1) the number of streets (12 through 36), (2) label point size (10, 12, and 14 point), (3) percentage of streets labeled (33, 66, 100 percent), (4) display location (high or low on the center console).

The results of the second laboratory experiment showed that labeled streets increased the response times more than the unlabeled streets for most of the tasks, and a maximum of 12 labeled streets should be used on the map to optimize search performance. The experiment also found that the use of 10 point text increased the response times for all tasks, especially for older drivers. In general 14 point text was preferred, although clutter effects were seen when using that point size on maps containing more than 16 labeled streets. The effect of display location was only tested using the first task, identify the street being driven. The higher location produced slightly faster response times (by 10 percent).

Issues

All of the initial work was conducted in a driving simulator to provide consistent test conditions and reduce cost. However, once the relationships of the key factors were established, it was necessary to determine the necessary adjustment of the laboratory data to predict on-the-road performance. Consequently, some of the test conditions from the previous simulator study (plus some additional conditions of interest) were explored on the road.

There were four key issues:

1. When do drivers feel that map reading is unsafe while driving?

Maps should not be so complex that they require an excessively long time to read. The major concern is that if drivers are not looking at the road, the risk of a crash increases. Prior to this research, there was a minimum of data on what drivers thought to be excessive. (See Hada, 1994 as an example.) One way to determine when drivers began to feel uncomfortable was to ask them to rate the tasks on a scale with regard to interference with driving and perceived safety.

2. What size text and how many streets should be displayed?

The first experiment tested only 12- and 18-point text sizes for street names, both of which are larger than the text used in some U.S. navigation systems. Unresolved was the impact of smaller font sizes on map reading times. Since the first experiment showed a large street's effect and an interaction between streets and text size, the number of streets displayed was also included as a factor in the on-the-road experiment.

3. How does the ambient lighting (time of day) affect map reading?

Altering the ambient light changes both the display contrast and its overall luminance level. The lighting levels in the UMTRI simulator approximated dusk. Although some adjustments can be made, limits of the scene projector output make simulating a wide range of conditions, especially daylight, difficult. (This is true of all driving simulators of which the authors are aware.) Accordingly, on-road driving was used to examine the effects of ambient lighting. Readers should remember that changes in scene luminance and interior illumination occur together, and furthermore, day-night differences were accompanied by changes in traffic volume.

4. How do the simulator results compare with the on-the-road results?

Experiments were conducted, for the most part, in the driving simulator because the conditions could be well controlled, especially traffic, leading to more stable results. Further, Michigan winters made collecting on-the-road data impossible. Rain in the spring and fall can likewise be problematic leading to schedule delays. Since the data was collected to predict on-the-road performance, differences between the two contexts were examined experimentally by replicating a subset of the test conditions from the driving-simulator experiment in the on-the-road experiment.

As an aside, the fourth experiment, which is in the planning stages as this report is being written, will consider when drivers want maps and when turn displays should be provided. The rationale is that for reasons of space and cost, only a single display may be available. The ideal situation would be for the navigation computer to "know" at any given moment which display format a driver might desire, and automatically present it, rather that forcing a driver to press a key each time a different format display should appear.

TEST PLAN

Test Participants

A total of 16 licensed drivers (8 men and 8 women equally drawn from two age groups) participated in the experiment. The subjects were randomly selected from the UMTRI human factors subject database of past subjects, friends of the staff, and those recruited through newspaper advertisements. Only those who had not participated in a previous map study or any other recent UMTRI study were recruited. Subjects were tested on one of two roads, M-14 or I-94, and in one of two time sequences, either day before night or night before day, with a minimum of three days between sessions. (See Table 1.) The eight subjects tested on M-14 were each paid $20 for each session with a bonus of $15 for completing both sessions. The I-94 subjects were paid an extra $10 paid to compensate for the longer drive to the test site. Three additional subjects were tested on M-14 but discarded to preserve a balanced design after the unexpected start of road construction required relocation of the test site.

Table 1. Subjects.

Road	Time Sequence (session 1, 2)	Young (19 - 25) (mean=22)		Mature (65 - 75) (mean=68)	
		Men	Women	Men	Women
M-14	Day, night	1	1	1	1
	Night, day	1	1	1	1
I-94	Day, night	1	1	1	1
	Night, day	1	1	1	1

Corrected visual acuity over all subjects ranged from 20/15 to 20/100 with means of 20/18 for younger subjects and 20/37 for older subjects. Seventy-five percent of the subjects wore either glasses or contacts.

Subjects drove an average of 12,000 miles per year with no differences due to age or gender. Only one subject had seen or used an in-vehicle navigation system, having participated in an on-road study of a navigation system four years ago (Green, Williams, Hoekstra, George, and Wen, 1993). Subjects reported, on average, that they had used maps 3 to 4 times over the past 6 months and that their computer use was daily, except for a few older subjects whose computer use was infrequent or never.

Test Activities and Their Sequence

Each subject began by completing a consent form (Appendix A), a biographical form (Appendix B), and having their vision checked. See Appendix C for the complete instructions to subjects.

Each experimental session consisted of two practice tasks and three experimental tasks. (See Table 2.) During each 8-minute, 24-trial sequence, subjects drove approximately 8 miles. An example or two of each task was shown to the subject before the start of the experiment while parked at UMTRI.

Table 2. Summary and order of session tasks.

Task	Description	Possible Responses
Practice 1 Task 1	Keypad practice What street are you on?	male or female
Task 2	What is the name of the first, third, fourth, or sixth cross street?	male, female, or not there
Practice 2 Task 3	Keypad practice Where is the named street?	ahead, behind, left, right, or not there

Each task was started after merging onto the expressway, and the start was indicated by the driver's display changing from the menu screen (displaying the UMTRI logo) to a black screen. To indicate the end of each task, the black screen reverted to the menu screen. Each trial began with an auditory alert (a "ding" for Task 1, the spoken target-cross-street number in Task 2, or the target-street name in Task 3). Subsequently, a hypothetical map (not corresponding to the road driven) was presented on the display while the subject drove. The subjects steered with their left hand while using their right hand (resting on the keypad) to press the appropriate response key. (See Figure 1.) All keys for all tasks were visible on the numeric keypad during the entire experiment. However, the software would only accept responses appropriate to the current task.

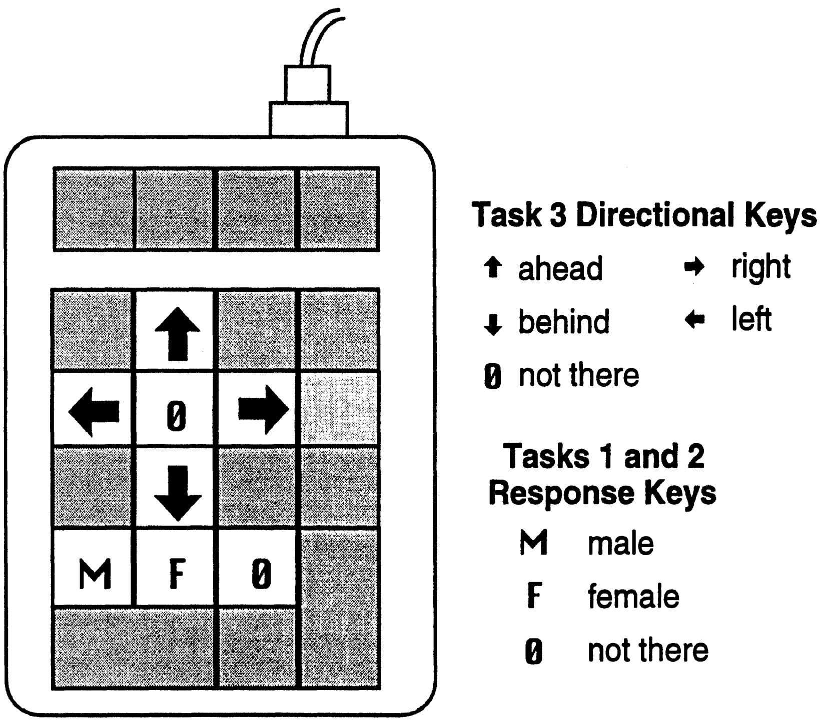


Figure 1. Response keypad layout.

Response times (measured to 1/60 of a second) and errors were recorded. If the subject answered correctly, the computer played a "beep." If the subject answered incorrectly or failed to answer within 25 seconds, the computer played a "buzz." The whole process repeated after an intertrial interval (ITI) randomly chosen between 10 and 12 seconds (in half-second increments). The intertrial interval was intended to allow sufficient time for drivers to recover from a trial and refocus their attention to driving. During the ITI the experimenter was able to pause the experiment, leading to a few trials (12 percent) with irregular ITI's ranging from 3 to 57 seconds. The experimenter paused the experiment whenever something occurred that would interfere with the subject's response such as subject questions, removing their hand from the keypad, or disruptive traffic (police car, tow truck, road obstruction, merging vehicle, and passing a slow-moving vehicle).

Map Construction

The maps were based on 4 street-templates. Maps contained either 12 or 24 streets. The 12-street maps were made by deleting 12 of the 24 streets on a 24-street map, thus resembling a "zoomed out" version of the 24-street map. Street labels were printed in 10-, 12-, or 14-point Helvetica. Street labels were oriented horizontally for horizontal streets and vertically for vertical streets as per the results of a previous experiment. Based on prior work to develop representative maps for the United States, all maps were based on a grid design containing one railroad and one river. All street names were common, unambiguously male or female names (according to a "baby book," Evans, 1994) ranging from 5 to 9 characters (lengths typical of US street names). Appendix D contains a sample of the maps used in this experiment and a discussion of the response time differences found between map templates. To partially counterbalance for order effects, each task contained a set of 24 trials (24 unique maps) shown in a fixed random sequence with each subject starting at 1 of 5 different points.

Task Descriptions

Practice 1: Keypad Practice (Male and Female)

To learn the association between the displayed names and the male and female response keys (used in Tasks 1 and 2), subjects were shown a series of 24 images such as the one in Figure 2. Subjects pressed one of two keys (left key = male and right key = female) for the gender of the name appearing on the screen. Subjects were instructed to respond as quickly and accurately as possible.

Each combination of the point size (10, 12, and 14) and gender was shown 4 times for a total of 24 trials. The orientation of the name (horizontal or vertical) was randomly chosen. The details of each trial appear in Appendix E. Due to an error on one 14-point slide, there were actually 5 replications of the male response and only 3 replications of the female response instead of 4 replications each. This should have no impact on any of the results.

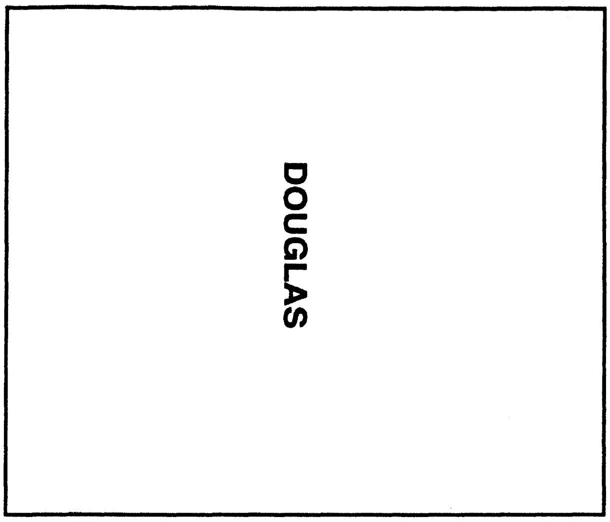


Figure 2. Practice 1. Example: The subject reads "DOUGLAS" and responds by pressing the "male" key.

Task 1: What Street Are You On?

Subjects were shown a series of 24 images such as the one in Figure 3. They looked for the vehicle icon (the arrowhead) on the street being driven, and then pressed the key associated with the gender of the street name (index finger=male, middle finger=female). Each possible combination of streets (12 and 24), point size (10, 12, and 14) and map template (4) was shown once for a total of 24 trials. Half of the responses in this task were male and half were female. Response gender was not included as an independent factor because the previous work showed no difference between male and female responses. The details of each trial can be found in Appendix E.

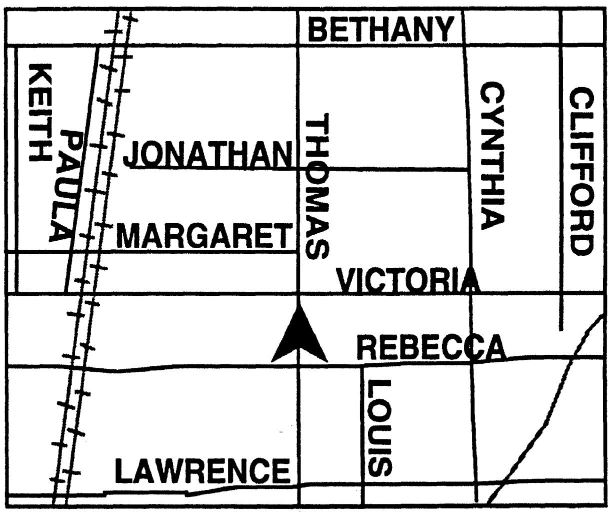
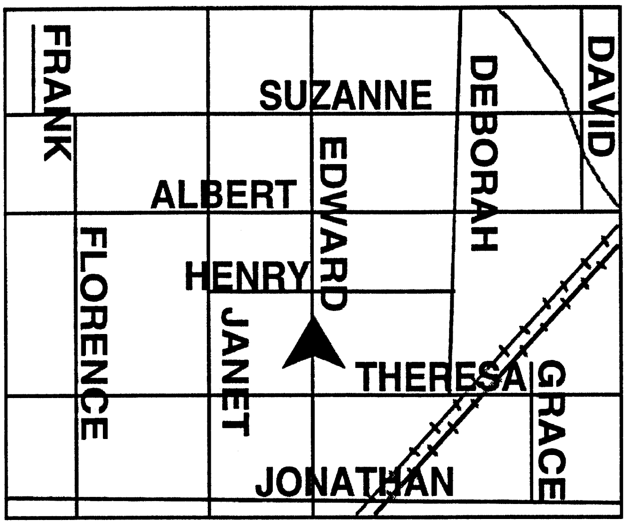


Figure 3. Task 1. Example: Thomas (male) is correct.

Task 2: What Is the nth Cross Street?

At the beginning of each trial, the computer played a digitized sound file of a person speaking a number. A map then appeared and the subjects looked for the corresponding cross street (e.g., "1" for the first cross street ahead of the vehicle icon showing their position, "3" for the third, and "4" for the fourth). If the named cross street was on the map, subjects pressed the key corresponding to the gender of the cross street name (as in Task 1; "m" for male or "f" for female). However, for some trials the named cross street did not appear on the map, whereby subjects pressed the key under their ring finger ("0") corresponding to "not there." This response simulated the situation of having a map with the wrong scale or showing the wrong area. A sample map appears in Figure 4.



Number read	Subject thinks:	Subject responds:
"1"	Henry	Male
"3"	Suzanne	Female
"4"	Not There	Not There

Figure 4. Task 2. Example slide.

In this task, there were two street levels (12 and 24), 4 possible cross streets which could be named (1, 3, 4, and 6), 3 responses (male, female, and not there), and 3 point sizes (10, 12 and 14). However, all possible combinations of these factors were not run due to practical limitations. (See Table 3.) Note that point size is blocked over cross street named, number of streets on the map, and between "there" (male and female) and "not there" responses. (As in Task 1, response gender was not treated as an independent variable.)

For the named cross streets 1 and 3, the "not there" response was not applicable because a minimum of 3 cross streets was needed for a natural looking street pattern. Similarly, a maximum of 4 cross streets could be fit on a 12-street map; thus 12-street maps contained either 3 or 4 cross streets. When the fourth cross street was named, the correct response was either "male" or "female" (if the map contained 4 cross streets) or "not there" (if the map contained only 3 cross streets). Naming the sixth cross street on a 12-street map would not be appropriate because the answer would always be "not there."

Table 3. Number of Task 2 trials per combination of cross street named, number of streets, and correct response.

Cross Street Named	12-Street Maps Correct Response: Male	Female	Not There	24-Street Maps Correct Response: Male	Female	Not There
1	0	3	N/A	1	2	N/A
3	2	1	N/A	3	0	N/A
4	1	2	3	N/A	N/A	N/A
6	N/A	N/A	N/A	2	1	3

In order to look natural, the 24-street maps contained either 5 or 6 cross streets. When the sixth cross street was named, the correct response was either "male" or "female" (if the map contained 6 cross streets) or "not there" (if the map contained only 5 cross streets). The fourth cross street was not tested on a 24-street map due to the limited amount of driving time during the task. Details of the experimental conditions can be found in Appendix E.

Practice 2: Keypad Practice (Arrow Keys)

The second practice task familiarized subjects with the basic decision process and response key mapping for Task 3 (Where is the target street?). Subjects reported the relative location of a target street with respect to vehicle marker icon. Possible responses were "ahead" or "behind," if the target street intersected the driven street in front of or behind the current location; "right," if the target was to the right of the driven street; "left," if the target was to the left of the driven street; or "not there," if the target was not on the map.

In Practice 2, the target street was indicated on the map by a thick line. (For "not there," no lines were thick). An example depicting a target street on the left is shown in Figure 5. Details of the experimental conditions can be found in Appendix E.

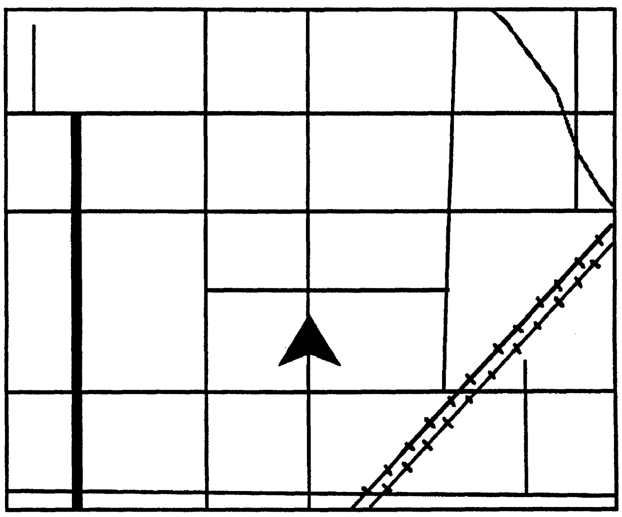
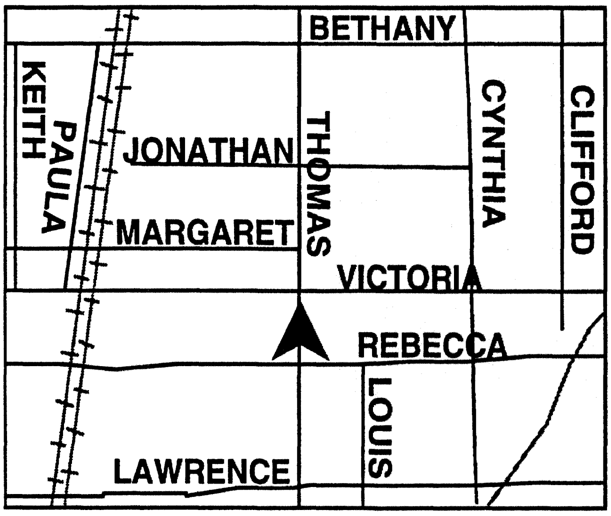


Figure 5. Practice 2. Example: The correct response is left.

Task 3: Where Is the Target Street?

Each trial began when the computer played a digitized sound file of a person speaking the name of the target street (e.g., Nancy). Then, a map appeared on the screen and the subject attempted to locate the target street on the map. The subject responded by identifying the target street's location on the map relative to the vehicle's current position (indicated by the vehicle icon). Response alternatives were "ahead, behind, left, right, or not there." Figure 6 shows an example map with the correct responses for a target street.



Name read	Subject answers:
Jonathan	Ahead
Lawrence	Behind
Keith	Left
Louis	Right
David	Not There

Figure 6. Task 3.

In each 24-trial block, all combinations of number of streets (12 and 24), point size (10, 12, 14) and response (ahead, behind, left/right, and not there) were shown once. The responses of left and right were combined into one category based on previous findings that left and right response times were not significantly different. (This pooling simplified the design of the experiment.) The details of each trial can be found in Appendix E.

Test Vehicle

The test vehicle was a 1992 left-hand drive Ford Taurus station wagon with an automatic transmission, power steering, and power brakes. This car was outfitted with a video recording system, a Macintosh computer, and a driver-accessible display and numeric keypad. (See Figure 7.)

Figure 7. Driver's view of the experimental setup.

The display was located relatively high and in front of the dashboard (typical of aftermarket navigation systems). Based on the measurements of a comfortably seated 6-foot-tall driver, the viewing distance from the eye to the center of the display was 31.2 in. The display location was 16 degrees below horizontal and 41 degrees to the right of center.

The video recording system consisted of two low-light cameras and one bullet (lipstick) camera. The bullet camera was hidden under the passenger's headrest and aimed at the speedometer to collect information on the vehicle's speed. One low-light camera was mounted to the headliner near the right rear passenger door to capture the forward road scene, part of the map display, and the right and left lane lines. The second low-light camera was mounted below the driver's display (aimed at the driver) to capture the driver's eye glances (between the road and the display). The three camera images (along with sound from a single piezometric microphone mounted on the dashboard) were combined using two two-way video splitters arranged in series to form one tri-screen image. (See Figure 8.)

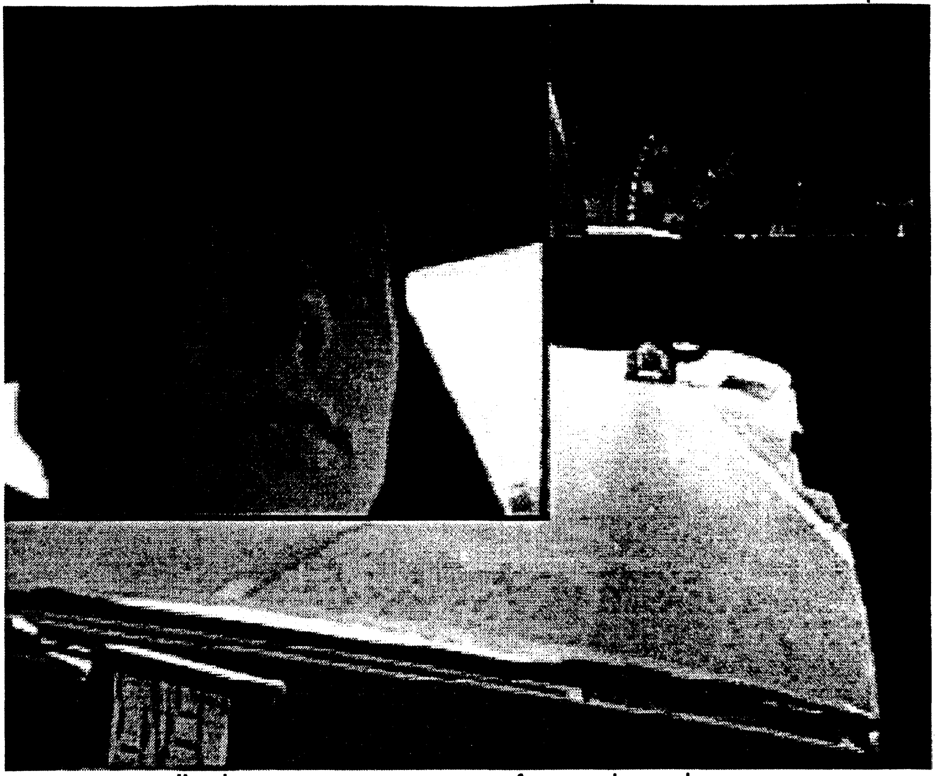


Figure 8. Typical tri-screen image.

The test vehicle also contained one Macintosh. The Macintosh video output was split to feed two LCDs, one for the driver and one for the experimenter. The software to display maps and time responses was written in SuperCard® 2.5. Sound from the Macintosh was transferred to the vehicle's stereo speakers through the tape deck using a standard compact-disc-player car-connection pack. Responses were collected using an external numeric keypad mounted within reach of the driver's right hand. The video equipment and computer were powered by a 110-volt AC power inverter connected to the car's electrical system. Appendix F shows a plan view of the test vehicle and the model numbers of all equipment in the vehicle.

All equipment was operated by the experimenter who was seated in the right-rear passenger seat. The experimenter's primary task was to monitor the traffic and the subject's driving. A second convex rear-view mirror located on the back of the driver's seat head rest allowed the experimenter to see vehicles approaching from behind or passing on the left of the test vehicle. The experimenter also controlled the VCR and monitored the cameras' output on an LCD display (Figure 9). The experimenter used a keyboard (with an integrated pointer) to control the Macintosh.

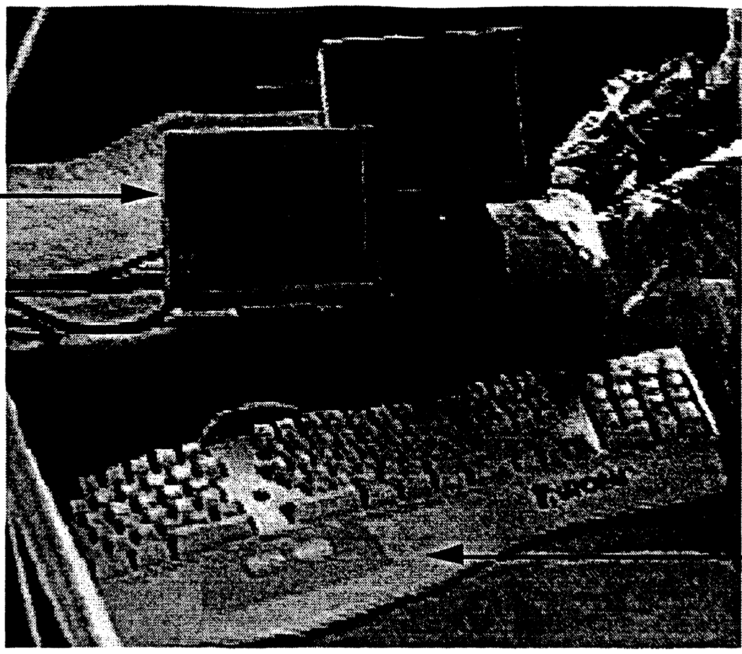


Figure 9. Some of the equipment operated by the experimenter (looking from right to left across the back seat).

Test Route

The experiment was designed to take place on an eight-mile section of a two-lane, limited-access road, M-14, between Ford Road (Exit 10) and Beck Road (Exit 18). The test section is located just northeast of Ann Arbor, Michigan. This road was chosen because it was relatively flat and straight with a fixed speed limit of 65 mph (raised by authorities to 70 mph in mid-experiment) Each task was designed to be completed within the eight-mile test section while traveling between 55 and 60 mph. Subjects were instructed to travel slower than the posted speed limit to minimize the amount of pausing required when passing slower moving vehicles. Subjects would then exit the expressway, turn around, and start the next task on the return trip, ultimately driving three complete loops from Ford Road to Beck Road and back during the course of the experiment. Each task ended prior to exiting the expressway. (See Appendix G for a map of the test route and a description of the task performed on each trip.)

Experimentation took place during the following off-peak times to keep traffic conditions relatively constant throughout the experiment: weekdays 9:00 to11:30 AM, 1:00 to 4:30 PM, 6:30 to 11:30 PM (excluding Fridays), weekends (1:00 - 4:30 PM) and Sundays (6:30 to 11:30 PM). Friday and Saturday nights were not used for testing because the traffic conditions were known to traditionally be above average. The night sessions started approximately one hour after sunset.

The experiment also took place only in good weather (no rain, snow, ice, or fog). Sessions that were canceled due to bad weather were rescheduled. Several sessions did encounter unexpected light drizzle or rain for part of a task, at which time the subject had the option of continuing. If the rain became hard enough to require constant use of the windshield wipers, the experiment was paused for several minutes to wait out the rain.

Unknown in advance, the Michigan Department of Transportation announced plans to close the M-14 segment for repairs while testing was in progress. Since approximately half of the testing had been completed, the experimental design was altered to allow for testing on a second road similar to M-14. A second test route segment on I-94 between Baker Road (Exit 167) and US 52 (Exit 159) was selected. The I-94 segment was actually less curvy than the M-14 route, but it contained more grade changes (hills). While this should not affect the response time in the map-reading task, more lane crossings were expected on M-14, and greater speed deviations were expected on I-94. The same procedure of running one task per eight-mile trip was used on the I-94 segment. (See Appendix G for a map of the test route and a description of the task performed on each trip.)

The I-94 route was also chosen because of its similarity in traffic volume to M-14. Traffic on I-94 (annual average daily traffic 49,460 vehicles) was only slightly heavier than the traffic on M-14 (annual average daily traffic 47,003 vehicles). However, the I-94 traffic contained more trucks (approximately 35 percent of the traffic volume versus 17 percent of the M-14 traffic). For both routes, the day sessions experienced approximately twice the hourly volume of traffic as night sessions.

RESULTS

Data Reduction

Four performance measures were independently analyzed in this experiment: (1) response time, (2) response errors, (3) lane excursions, and (4) unintentional instances of speed decrease. Response time and response errors were recorded by the software written to display the maps. Lane excursions and speed decreases were obtained from a slow speed playback of the session videotapes using a frame-accurate VCR. Additionally while watching the session videotapes for lane excursions and speed decreases, the analyst recorded the number of glances between the roadway and the display while a map was being shown for each trial.

Response time was defined as the time (measured in ticks or sixtieths of a second) between a map's appearance and when the subject pressed a key on the keypad. Any response faster than 150 ms was automatically disregarded as accidental keystrokes, and the subject was allowed to continue the trial and respond a second time. Based on the quickest response times seen in previous experiments, responses between 150 ms and 400 ms were flagged as being possibly too fast, but the trial was counted as completed. Only one response in this category occurred during the experiment and the subject immediately confirmed that the keystroke was unintentional.

The analyst also noted response times which were possibly suspect because the subject (1) was not ready for the trial to begin (e.g., asked a question during the trial or moved his or her hand from the keypad); (2) was distracted by traffic; or (3) could not hear or understand the number (Task 2) or name (Task 3) of the target street as it was read. Suspect response times were replaced with a mean if the specific response time was an outlier. (An outlier was defined as any trial response time which exceeded the subject's task mean response time plus 4 times the standard deviation.)

There were initially no suspect trials in Task 1, but further analysis revealed 2 outliers in excess of 10 seconds which were replaced by the subject's average response time for similar point size and street level across the 4 map templates. (Note: Each task contained 768 trials.) In Task 2, there were six suspect trials, 3 of which were considered outliers and replaced with the subject's average response time across point size for a similar number of streets and cross street named. In Task 3, there were no outliers and none of the five suspect trials were replaced. A list of trials removed is contained in Appendix H.

A response error was defined as whether or not the subject answered the trial correctly. Where possible, the experimenter noted the any obvious explanations for each error or any subject comments. (Sometimes the subjects would explain the reason for the error immediately following the trial such as saying, "I hit the wrong key," or, "I really meant to a press....")

There were two driving performance measures: lane excursions and unintended speed decreases. Lane excursions occurred when drivers paid excessive attention to the map display (diverting attention from steering) and allowed the vehicle to cross either the left- or right-lane marker. Because the experimenter was constantly monitoring the traffic and the subject's driving, there was minimal risk when lane excursions occurred. To assist in judging when lane excursions occurred, the forward-looking camera was positioned to capture both edge lane lines for the lane driven. The videotaped image was then compared to two reference images showing the vehicle at the threshold of crossing the lane marker. (See Appendix I.)

Unintended speed decreases were characterized by a constant speed decrease during the trial while the subject attended to the map followed by a rapid acceleration after the trial when the subject realized that their speed had dropped. In the video analysis, the speedometer camera was used to judge the speed drop during the trials (only decreases greater than 3 mph could be accurately detected using this method). Some speed losses were due to nonexperimental factors evident in the video (such as traffic slowing ahead) and were not counted as an unintended speed decrease.

Task 1: What Street Are You On?

Errors

The overall task error rate was 1.8 percent (14 out of 768 trials). The few errors appear random and are described in Appendix J. Several subjects reported confusion between the name Michelle and Michael, but neither name was missed more than would be expected due to random errors.

Response Time

The response times for Task 1 ranged from 933 to 7000 ms with a mean of 1790 ms (standard deviation = 690 ms). Figure 10 shows the distribution and the cumulative distribution of response times measured during this task. Ninety-five percent of the response times were under approximately 3 seconds.

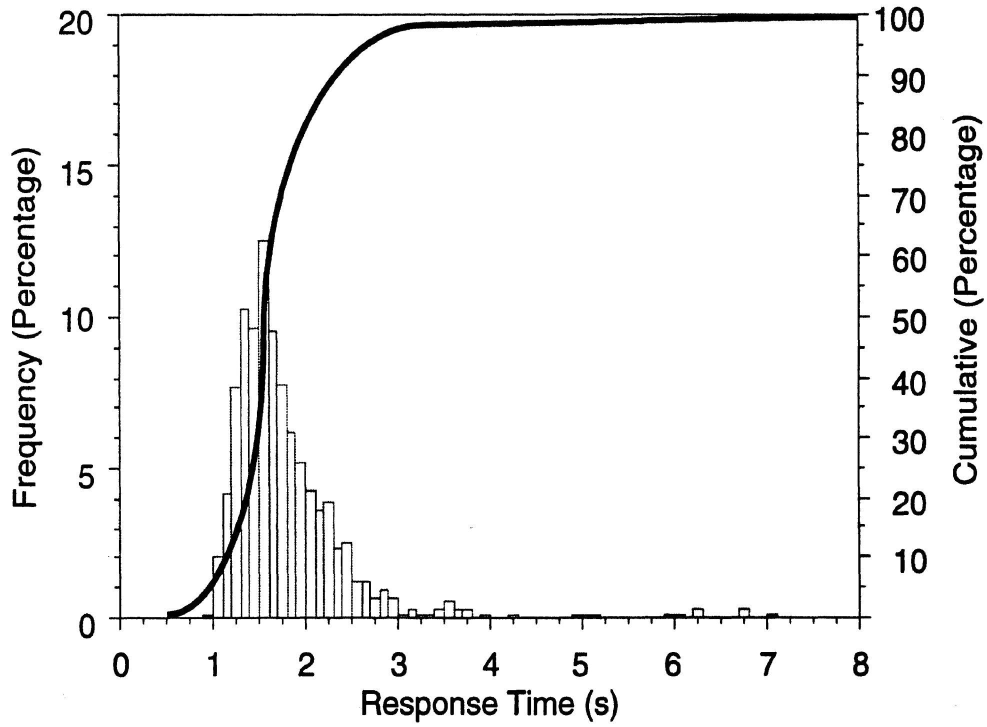


Figure 10. Task 1: Distribution of response times.

The response-time analysis used a repeated measures ANOVA model. Table 4 summarizes the main effects and significant two-factor interactions examined in Task 1. The more detailed ANOVA for Task 1 (not including higher order interactions) appears in Appendix K.

Table 4. Task 1: Response time main effects summary.

Effect Category	Factor	Effect Type (between, within, mixed)	P-Value
Subject	age	between	<.001
	gender	between	.79
	age*gender	between	.76
Context	road	between	.17
	time of day	within	.13
	time sequence	between	.28
	time* time sequence	mixed	.37
	map template	within	.10
Map Design	point size	within	.028
	number of streets	within	.055
	streets*point size	within	.043

Subject Effects (Age and Gender)

The only subject effect found to be statistically significant was age. The difference between mature subjects (mean 2120 ms) and young subjects (mean 1470 ms) was 650 ms (an increase of 44 percent). Gender was not significant nor was the age-by-gender interaction (the mean absolute difference between men and women of only 35 ms). Variability increased with the subject age (280 ms for young subjects, 810 ms for mature subjects). Figure 11 shows the effects of age and gender.

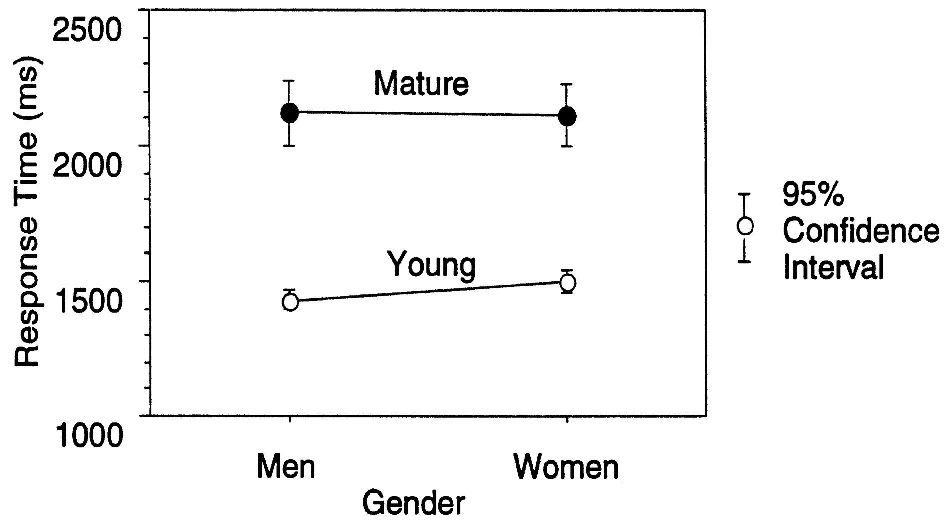


Figure 11. Task 1: Effects of age and gender on response time.

Context Effects (Road, Time of Day, and Map Template)

The effects of map template (a maximum difference between any two templates of 125 ms) and road (a 95 ms difference) were not found to be significant; however, a more detailed discussion of each effect can be found in Appendix D and G, respectively.

The day-night differences were examined within each subject; however, since each subject could complete only one session first, the time of day effect is confounded with practice effects. Day-night sequences were counterbalanced between subjects to allow a partial separation of the practice effects from the time-of-day effects. Overall, there was no significant difference between day and night. The time-sequence effect and the time-of-day-by-time-sequence interaction were also not significant. However, when the night session was first (Figure 12), the response times were increased by 15 percent (270 ms). Although this hypothesis was not tested, apparently learning the task at night was more difficult.

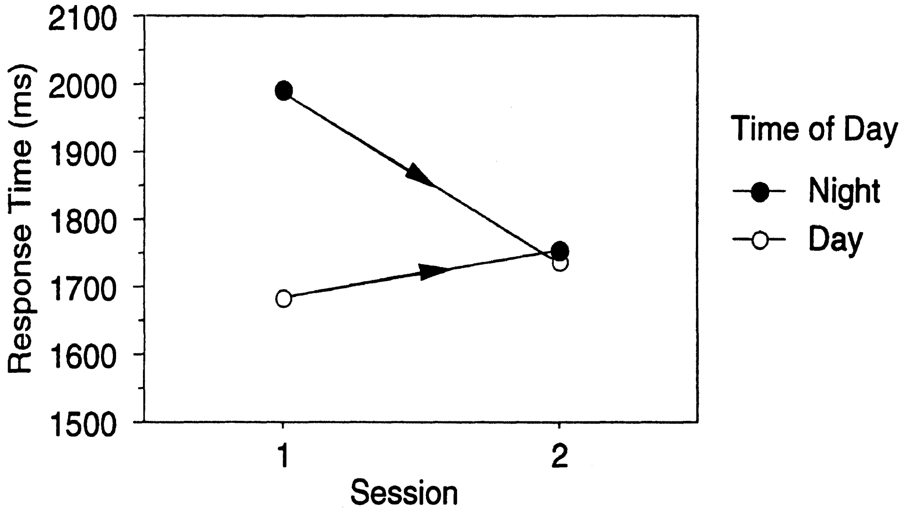


Figure 12. Task 1: Effects of time of day and session on response time.

Map Design Effects (Number of Streets and Point Size)

Both the number of streets shown on the map and the point size were found to be significant. As the number of streets increased from 12 to 24, the response time increased by 4.5 percent (80 ms). As the point size decreased from 12 point to 10 point, the response times increased by 10.5 percent (180 ms). In addition to the streets effect and the point-size effect, the streets-by-point-size interaction was significant. The 14 point labels appeared to be as good as the 12 point labels when only 12 streets were shown. However, the subjects had difficulty reading the 14 point labels when 24 streets were shown (apparently due to clutter).

Figure 13 shows that, among younger subjects, the map design factors had little effect, and the effects reported are due mainly to the differences found in mature subjects. The 10 point always produced the slowest response times in mature subjects (approximately 15 percent or 300 ms worse than 12 point). Additionally, 65 percent of the long trials (over 4 s) occurred when mature subjects were viewing maps labeled in

10 point. Two mature women commented during the experiment that they had difficulty reading the 10-point street labels.

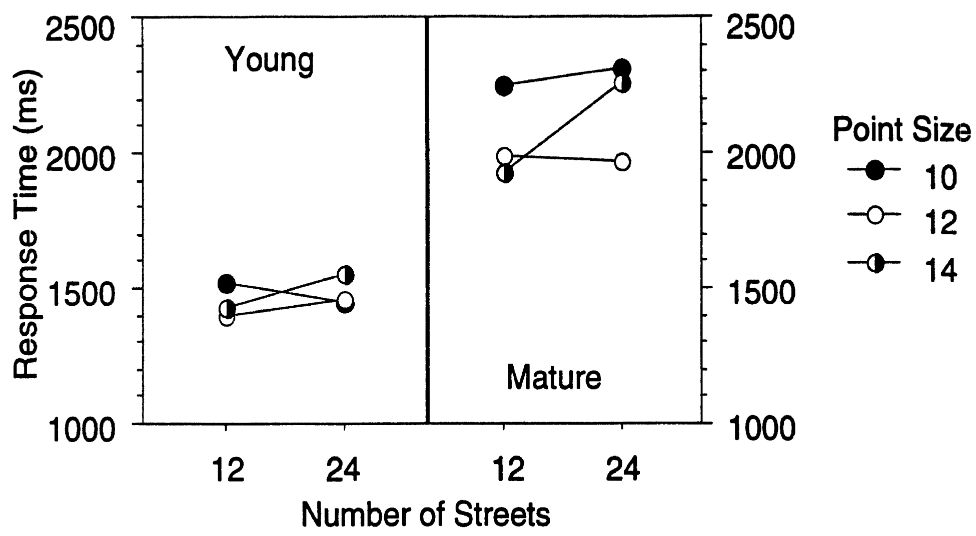


Figure 13. Task 1: Effects of point size and number of streets on response time.

Task 1 Response Time Prediction Model

The basic model for predicting the Task 1 response time contains 4 factors: age, the number of streets shown on the map, the label point size, and clutter. Both age and the number of streets are modeled as linear effects. Label point size appeared to contain a local optimum (near 12 point) with an increasing response time for both smaller and larger point sizes; hence a quadratic function was chosen as the simplest way to model this effect. Clutter is modeled as the interaction between label point size and the number of streets on the map

$$\text{Response Time (ms)} = 6710 + 325{*}(A) + 6.67{*}(S) + 33.75{*}(P)^2 - 832.50{*}(P) + 9.58{*}(C)$$

where

$$A = \text{Age} \begin{cases} -1 \text{ for young subjects} \\ +1 \text{ for mature subjects} \end{cases}$$

S = Number of streets ($S \geq 1$)

P = Label point size ($10 \leq P \leq 14$)

$$C = \text{Clutter} \begin{cases} 0 \text{ for point size } \leq 12 \\ (P-12)(S-12.52) \text{ for point size } > 12 \end{cases}$$

The model predictions accounted for 90 percent of the Task 1 response time variance (using an uncorrected R-squared). (See Figure 14.) The model does not, however, predict the upper 5 percent of the response times (those above 3000 ms).

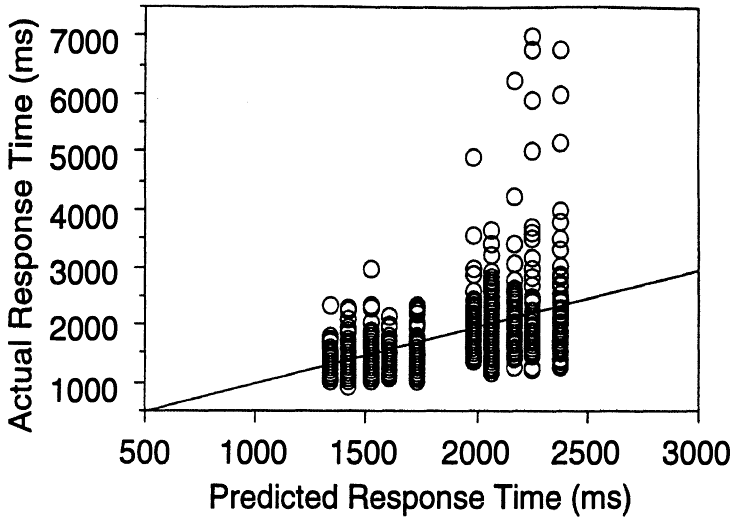


Figure 14. Task 1: Predicted response time vs. actual response time.

Driving Performance

Overall, subjects were able to perform the on-street map-reading task without any driving performance loss. Only 5 lane excursions and no unintentional instances of speed decrease occurred during Task 1. The 5 errors were not related to any factors analyzed in this experiment.

Task 2: What Is the nth Cross Street?

Errors

The overall Task 2 error rate was 11.6 percent (89 out of 768 trials). Errors were not uniformly distributed among slides since 56.2 percent of the errors occurred on only 4 slides (out of 24) whose individual error rates ranged from 30 to 50 percent. There were two reasons why these 4 maps were error prone. First, even though the street labels were placed with care to avoid overlapping cross streets, two of the maps were extremely cluttered (both were 24-street maps) and the on-street label masked an intersection. The common error for these maps was to miss the masked cross street and answer as if there were one fewer cross street on the map. Second, high error rates occurred when all of the cross street names appeared stacked on one side of the on-street, but one of the stacked names was not a cross street. Subjects generally counted all of the stacked names and answered as if the map contained one extra cross street.

Subject Effects (Age and Gender)

Subject age had an effect on error rate, but subject gender did not. Mature subjects made 58.1 percent more errors than younger subjects, but note that error rates varied widely between subjects. (See Table 5.)

Table 5. Task 2: Number of errors per subject.

Age	Gender	Subject	Response Time (ms)	Number of Errors
Young	Male	1	2080	4
		2	2730	4
		3	3100	2
		4	3110	4
	Female	1	3390	2
		2	2350	2
		3	2730	6
		4	2850	5
Mature	Male	1	3890	8
		2	4120	9
		3	3460	6
		4	4230	10
	Female	1	4010	9
		2	3130	5
		3	2950	4
		4	4720	9

There is a statistically significant correlation ($p < .001$) between the subjects' response times and error rates ($r = .79$). To determine if all subjects were performing at a similar trade-off between speed and accuracy (i.e., some subjects were not sacrificing accuracy for fast response times), a speed-accuracy operating characteristic curve was computed for the pool of test subjects. (See Figure 15.) Subject performance could generally be classified as either good (fast response times and high accuracy) or poor (slow response times and low accuracy) with more of the mature subjects falling into the later category.

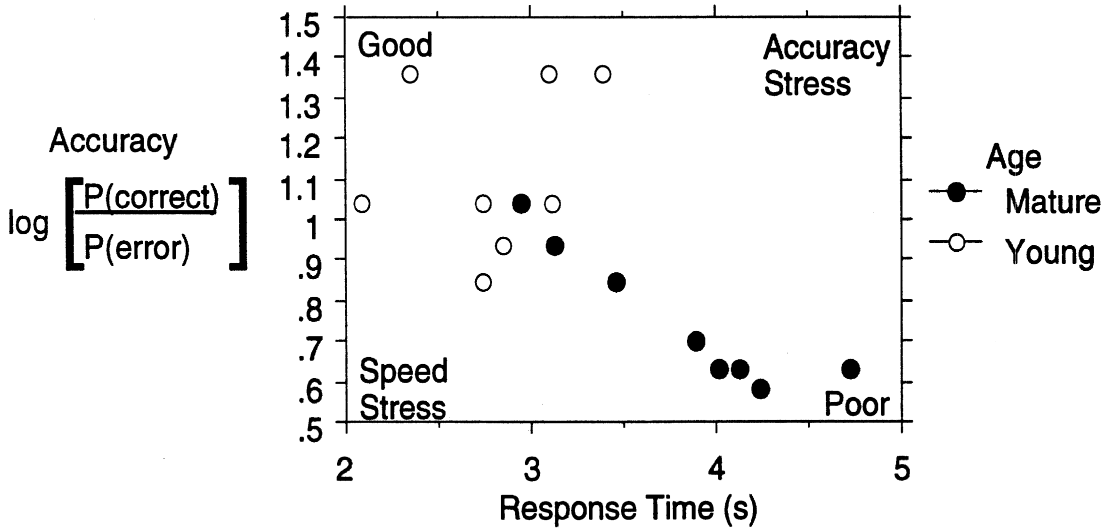


Figure 15. Task 2: Speed-accuracy operating characteristics across subjects.

Context Effects

The task error rate was not affected by the road being driven on or the time of day, however, there was a learning effect as shown in Figure 16. Errors were not evenly and randomly distributed throughout the duration of the task. Approximately 42 percent of the errors occurred in the first 6 trials shown during the task (regardless of session).

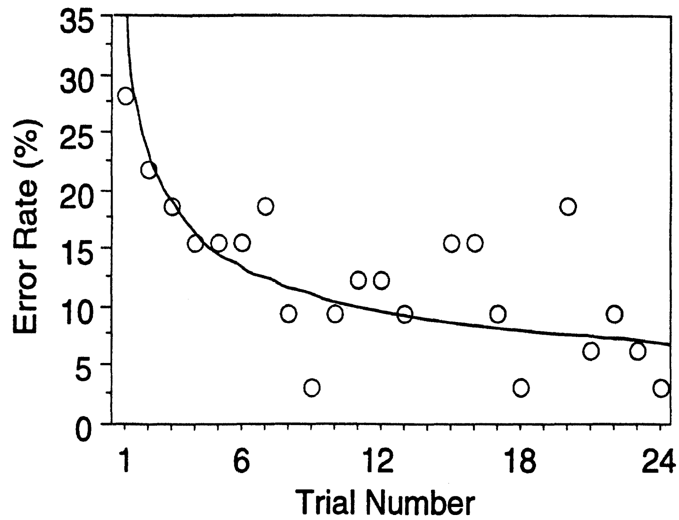


Figure 16. Task 2: Effect of learning on error rate.

Map Design Effects

While label point size did not appear to affect the error rate, both the number of streets on the map and the cross street named influenced the error rate. As shown in Figure 17, increasing the number of streets on the map from 12 to 24 consistently increased the error rate. Similarly, increasing the number of the target cross street increased the error rate; however, an unexpectedly high error rate occurred when the third target cross street was named on a 24-street map.

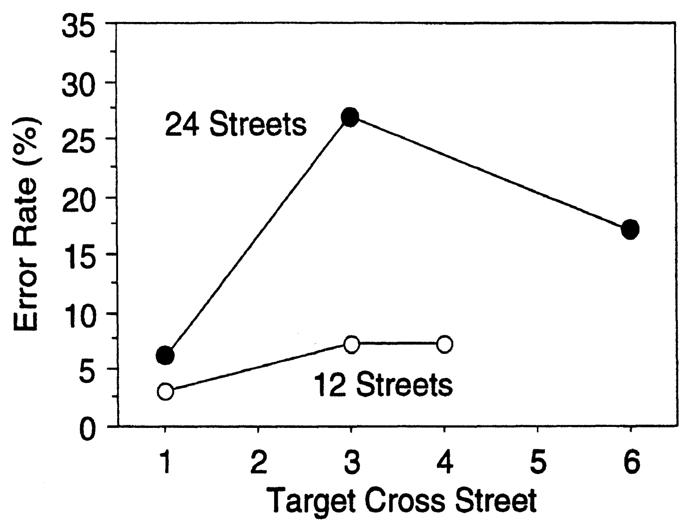


Figure 17. Task 2: Effects of cross street named and number of streets on the map.

Response Time

The response times for Task 2 ranged from 1050 to 13930 ms with a mean of 3370 ms (standard deviation = 1780 ms). Figure 18 shows the distribution and the cumulative distribution of response times measured during this task.

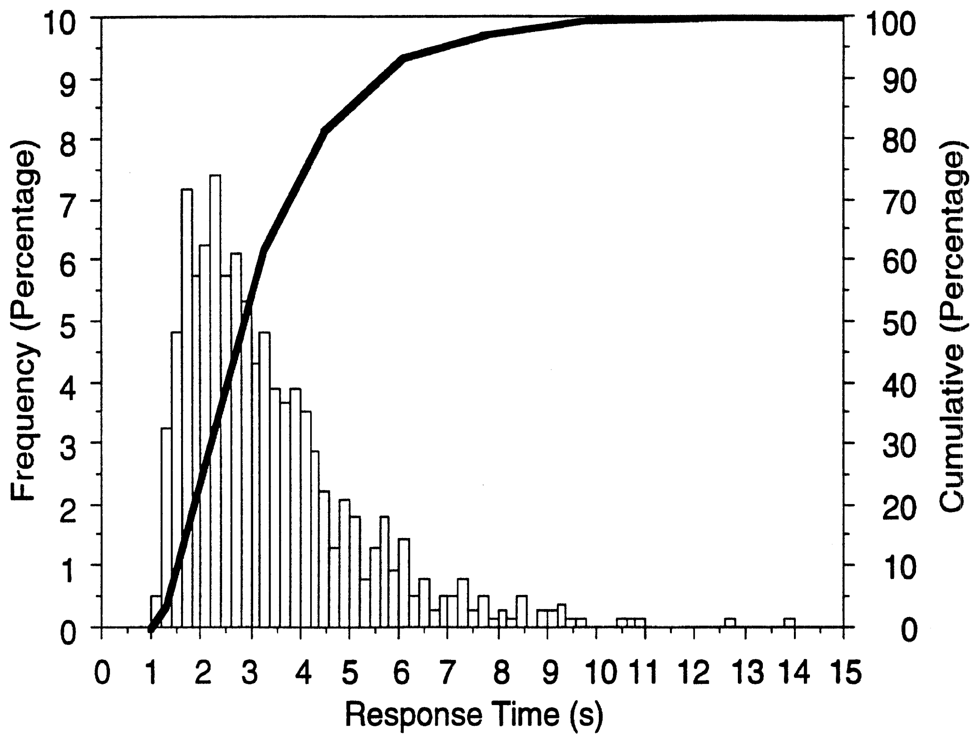


Figure 18. Task 2: Distribution of response times.

The response time analysis used a repeated measures ANOVA model. Table 6 summarizes the main effects examined in Task 2. Higher order interactions were computed but not reported in the more detailed Task 2 ANOVA found in Appendix L.

Table 6. Task 2: Response time main effects and significant interactions summary.

Effect Category	Factor	Effect Type (between, within, mixed)	P-Value
Subject	age	between	.0015
	gender	between	.85
	age*gender	between	.94
Context	road	between	.83
	time of day	within	.37
	time sequence	between	.24
	time*time sequence	mixed	.066
Map Design	condition	within	<.001
	point size	within	.87
	point size*condition	within	<.001

Subject Effects (Age and Gender)

Age was the only statistically significant subject effect. The difference between mature subjects (mean 3940 ms) and young subjects (mean 2790 ms) was 1150 ms (an increase of 41 percent). Neither gender nor the age by gender interaction was significant with a mean absolute difference between men and women of only 50 ms. Figure 19 illustrates the effects of age and gender.

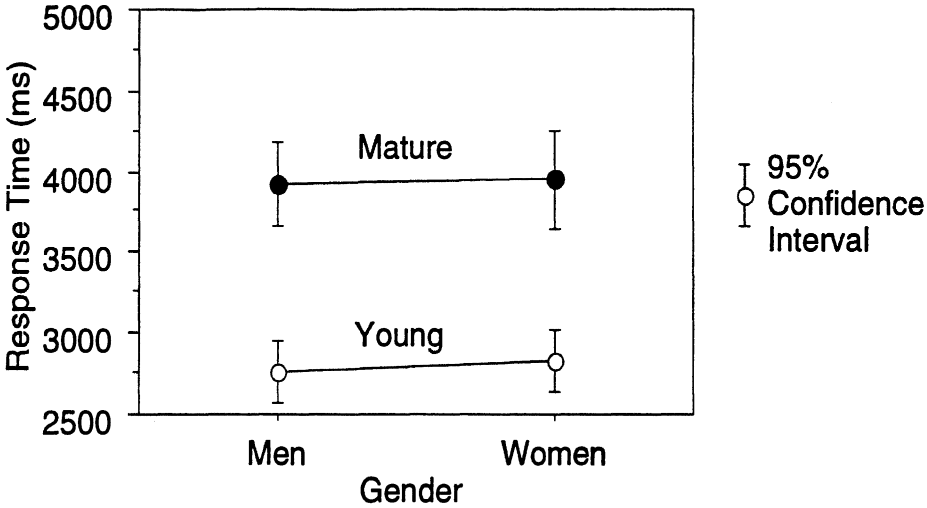


Figure 19. Task 2: Effects of age and gender on response time.

Context Effects (Road, Session, and Time of Day)

The road effect was negligible with a mean difference between roads of only 60 ms. There was, however, a large learning effect between sessions. (See Figure 20.) Response times decreased an average of 13.3 percent (420 ms) between session 1 and session 2. There was a slight increase in response times (190 ms) for night sessions, but the time of day effect was not significant. As in Task 1, learning the task at night was apparently more difficult as the improvement between sessions experienced by subjects starting on the night condition was nearly three times that of subjects starting on the day condition.

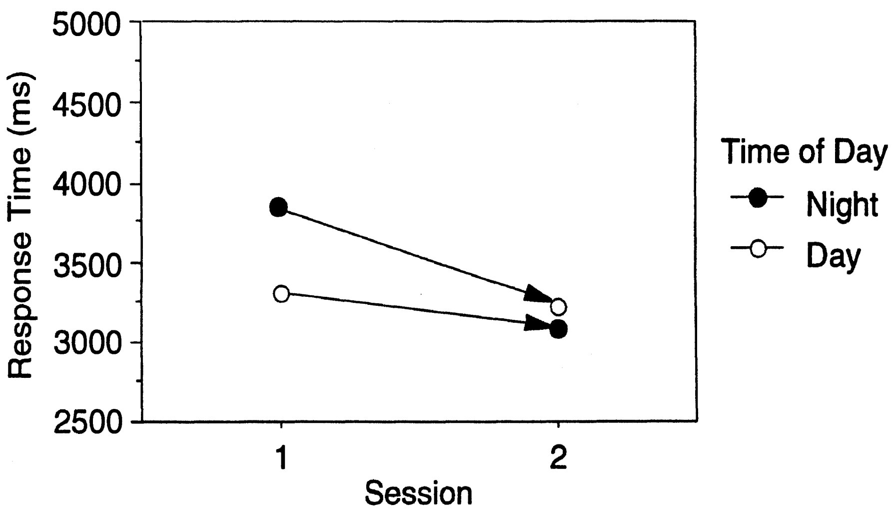


Figure 20. Task 2: Session learning effect.

Map Design Effects (Condition and Point Size)

The variable condition represents the 8 unique combinations of the number of streets, cross street named, and response, which were all run at each level of point size (for a total of 24 trials). The condition effect was significant which means that at least one of the 8 conditions was more difficult than the rest, but because a full factorial model with equal cell sizes was not possible, the factors of interest were examined using linear contrasts. (See Table 7.) Note that the number-of-streets effect, cross-street-named effect and streets-by-cross-street interaction are based on only the data for the named cross streets of 1 and 3.

Table 7. Task 2: Linear contrasts for the condition effect.

Factor	P-Value
number of streets	.0039
cross street named (1 or 3)	<.001
streets by cross street	.0042
response of "not there"	.52

The average response time to count up 1 cross street was 2070 ms regardless of the number of streets on the map. (See Figure 21.) The response times then increased mainly in proportion to the cross street named by approximately 370 ms per additional street. An increase in the number of streets on the map from 12 to 24 generally increased the response times by 36 percent (1010 ms).

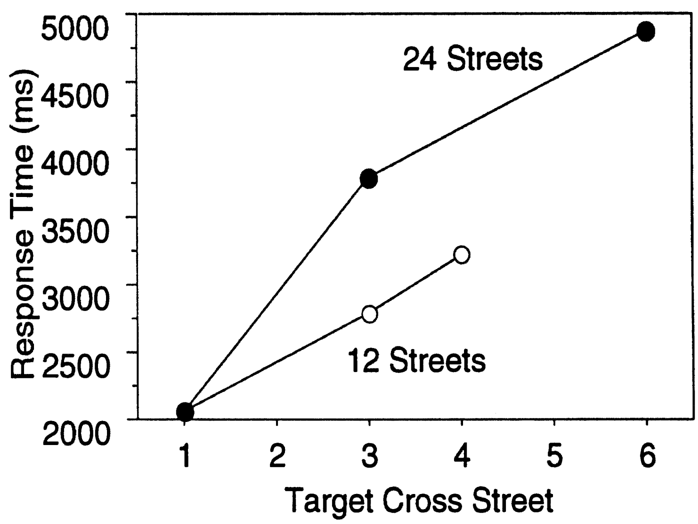


Figure 21. Task 2: Effects of cross street named and number of streets.

The main effect of label point size was not significant. The largest mean difference between any two point sizes was under 50 ms. However, the interaction between the number of streets and point size was significant as shown in Figure 22. For the low detail maps (12 streets), decreasing the point size increased the response times by 13 percent (340 ms). For the more detailed maps (24 streets), increasing the point size increased the response times by 12 percent (440 ms). Hence, in designing maps, increasing text size (intended to enhance legibility) can degrade readability when the maps become too cluttered.

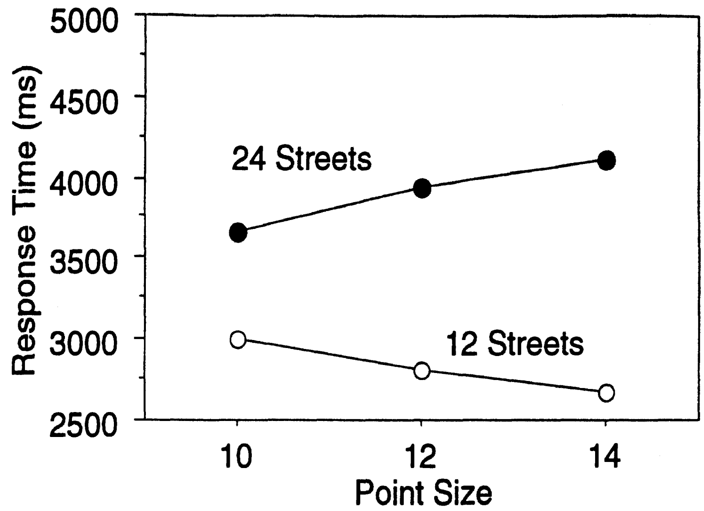


Figure 22. Task 2: Interaction between point size and number of streets.

Task 2 Response Time Prediction Model

The basic model for predicting the Task 2 response time contains 4 factors: age, target cross street, the number of streets shown, and point size. The first 3 terms in the model represent the linear effects of age, target cross street, and the number of streets shown. The next term represents the interaction between the number of streets and the target cross street, which in essence reduces the effect of number of streets when the target cross street is near the vehicle icon. The final term in the model shows the effects of clutter through the interaction of number of streets shown and point size.

$$\text{Response Time} = 1210 + 575^*(A) + 370^*(X) + 40.83^*(S) + 40.83^*(S-12)^*[\text{MINIMUM}(1,X-2)] + 8.08^*(P-12)^*(SL)$$

where

$$A = \text{Age} \begin{cases} -1 \text{ for young subjects} \\ +1 \text{ for mature subjects} \end{cases}$$

X = Target Cross Street ($X \geq 1$)

S = Number of streets ($S \geq 1$)

P = Label point size ($10 \leq P \leq 14$)

$$SL = \text{Street Level} \begin{cases} -1*(24-S) \text{ for } S \leq 12 \\ +1*(S-12) \text{ for } S > 12 \end{cases}$$

The model predictions were plotted against the actual response time with an uncorrected R^2 of 88 percent for all 768 Task 2 trials. (See Figure 23.)

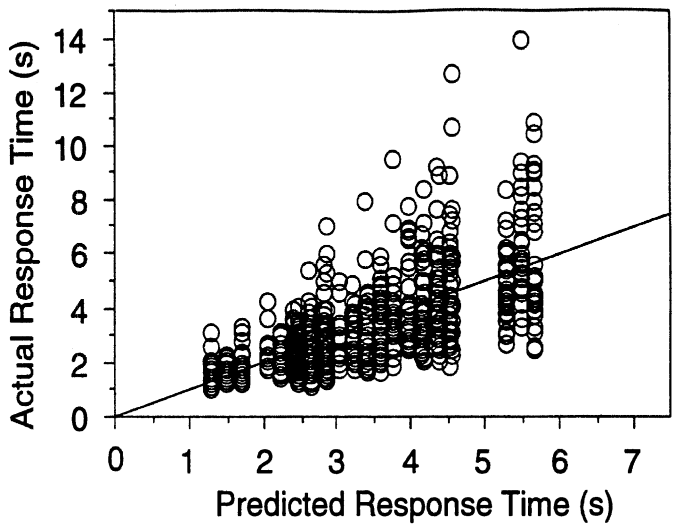


Figure 23. Task 2: Predicted response time vs. actual response time.

Driving Performance

Lane excursions occurred during 3.1 percent (24 of the 768 trials) while unintentional speed decreases occurred during 2.1 percent (16 of the trials). They occurred jointly only once, which is what was expected if they were independent (between 0 and 1 error). As shown in Table 8, driver performance varied greatly between subjects. Generally, mature subjects were 3 times more likely to commit a driving error during this task than were younger subjects, and women were about 1.5 times more likely to commit a driving error than were men.

Table 8. Task 2: Number of driving performance errors per subject.

Age	Gender	Subject	Response Time (ms)	Lane Excursions	Speed Decreases
Young	Male	1	2080	0	0
		2	2730	1	0
		3	3100	1	1
		4	3110	0	0
	Female	1	3390	1	0
		2	2350	0	2
		3	2730	0	1
		4	2850	2	0
Mature	Male	1	3890	7	1
		2	4120	1	0
		3	3460	1	0
		4	4230	1	1
	Female	1	4010	4	4
		2	3130	2	3
		3	2950	1	0
		4	4720	2	3

Driving errors were significantly correlated ($p < .001$) with longer trial response times ($r = .26$). Trials during which a driving error occurred had a 65 percent (2120 ms) longer response time. However, in most cases subjects noticed the unintentional lane excursion or the speed decrease and attempted to correct for the driving error before finishing the trial, thus increasing his or her response time and making it difficult to separate whether the errors were caused by or caused longer response times.

As shown in Figure 24, for a single glance to the display, 80 percent of the driving errors occurred when the response time exceeded 2.5 seconds. For multiple glances to the display, 70 percent of the driving errors occurred when the response time exceeded 5 seconds.

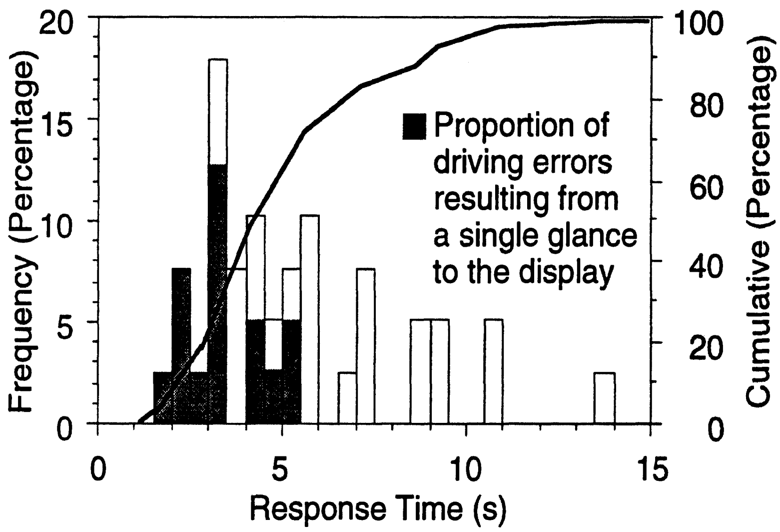


Figure 24. Task 2: Distribution of trial response times resulting in a driving error.

One problem with a frequency analysis in this experiment was that the number of trials or exposure was not evenly distributed in each response time category. Although there were numerically more driving errors during responses below 5 seconds, the probability of a driving error appeared to be lower, and the probability generally increased as the response time increased. (See Figure 25.)

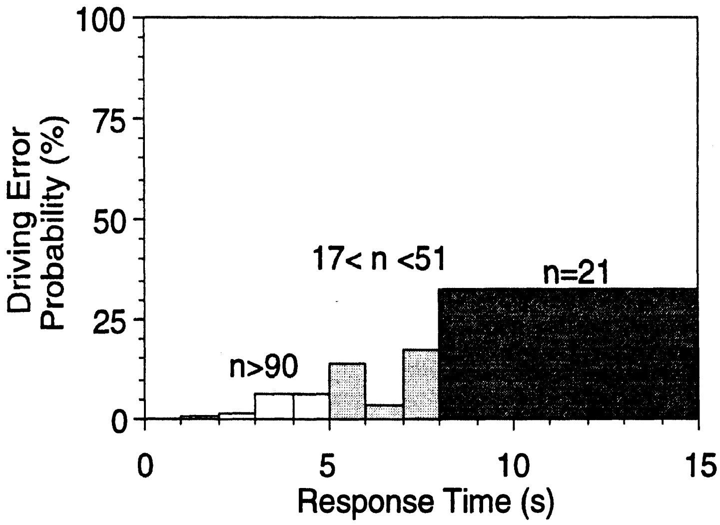


Figure 25. Task 2: Probability of a driving error given response time.

Since driver errors were correlated with longer response times, it would be expected that the label point size would have no effect on the number of driving errors, but the map condition would. As shown in Figure 26, increasing the number of cross streets to be counted substantially increased frequency of driving errors. Limiting the number of labeled cross streets may therefore be desired. Finally, driving errors were not well correlated with task response errors (r = .083). Only 23 percent of the trials with driving errors (9 out of 39) resulted in a response error.

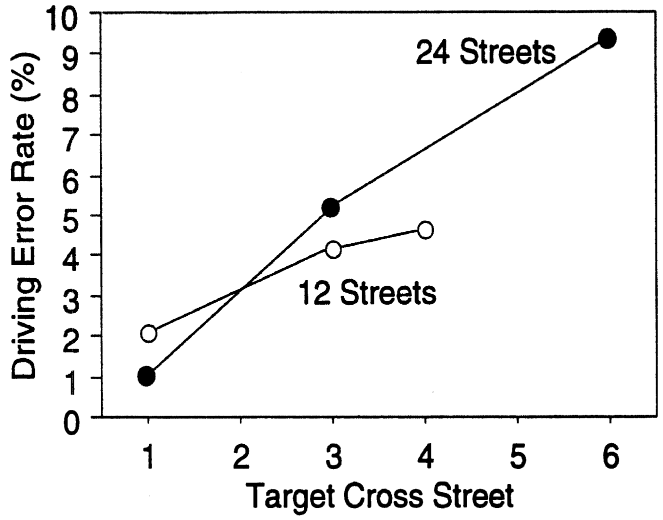


Figure 26. Task 2: Driving error rate for each map condition.

Task 3: Where Is the Target Street?

Errors

The overall task error rate was 13.3 percent (102 out of 768 trials). Table 9 summarizes the errors partitioned by response. Errors fell into three categories: slips, response confusion and location errors, and misses.

Table 9. Summary of the Task 3 errors split by response.

	Response					
Stimuli	ahead	behind	left	right	not there	Total
ahead	**170**	0	5	0	17	192
behind	1	**160**	6	3	22	192
left	1	2	**67**	0	26	96
right	4	5	0	**78**	9	96
not there	0	1	0	0	**191**	192
Total	176	168	78	81	265	768

Note: The cells in bold are correct responses.

A slip occurred when the subject unintentionally hit the wrong key. For many slips, subjects immediately realized they made a mistake and said so to the experimenter. Slips also occurred when subjects returned their right hand to the keyboard (after performing some other task) but did not align their hand with the correct response keys. For example, if shifted one key right, pressing what they thought was the left arrow key resulted in a "not there" response. Slips comprised about 7 percent of the errors and did not significantly affect the subjects' response times for this task. (The removal of slip errors increased the task mean by only 10 ms.)

Response confusion or location errors, the second category, comprised about 23 percent of the errors. This type of error occurred when the subject found the target name on the map but responded with the wrong location typically for one of two reasons. First, the subject may have correctly identified the target street and its location but became confused about which keypad response was correct. This was due to the rather arbitrary rule for separating right and left from ahead and behind. The rule stated that any street intersecting the street with the vehicle icon was either ahead or behind and all others could only be left or right; however, some subjects would forget the rule during a trial and misclassify the street. A second common reason for missing the location of the street was a disassociation between the street name location and the street location. The most common example of a location error was on slide 17. The target name was "Sarah," and the street was located to the right of the vehicle icon running parallel to the street on which the subject was traveling. The name "Sarah," however, was located along that street towards the bottom of the screen. The subjects answered "behind" because the street name was behind, even though the street was obviously to the right. Response confusion and response location errors did not significantly affect the subjects' response times for this task. (The removal of response confusion errors and location errors reduced the task mean by only 15 ms.)

In describing the third response error (misses), it is useful to characterize Task 3 as a signal detection task (Table 10). A miss occurred when the subject responded "not there" when the target street was actually on the map. Misses accounted for 70 percent of the error responses. The response time for a miss was similar to the response time for a correct rejection because both required and exhaustive search of the map. Misses and correct rejections resulted in response times 59 percent greater than those of hits, and deleting misses from the data set decreased the task's overall mean response time by 260 ms.

Table 10. Task 3 as a signal detection task.

	Stimuli: ahead, behind, left or right			Stimuli: not there		
Response	Outcome	%	(ms)	Outcome	%	(ms)
ahead, behind left or right	Hit	87.2	4950	False Alarm	0.5	5270
not there	Miss	12.8	7890	Correct Rejection	99.5	7170

There were two errors not included in the previous categories. The first was a "behind" response on a slide whose correct answer was "not there." The subject gave no clue as to whether this error was a slip or a false alarm (from signal detection theory). The second error occurred when the subject drove over a bump and accidentally hit a key prematurely, in which case no response was intended.

Factors Influencing Error Rate

The error analysis for Task 3 used a repeated measures ANOVA model because there was a sufficient number of error trials in this task to draw meaningful conclusions using this method. Admittedly, treating the error data (binary) as a continuous dependent variable violates the assumptions of the standard ANOVA model. The p-values reported were only used to screen effects. Table 11 summarizes the main effects and significant interactions examined in the Task 3 error analysis. A more detailed ANOVA for the Task 3 error rate appears in Appendix M.

Table 11. Task 3: Error rate main effects and significant interactions summary.

Effect Cagegory	Factor	Effect Type (between, within, mixed)	P-Value
Subject	age	between	<.001
	gender	between	.63
Context	road	between	.11
	time sequence	between	1.00
	time of day	within	.19
	time*time sequence	mixed	.50
	response location	within	<.001
	location*age	mixed	<.001
Map Design	number of streets	within	.0017
	point size	within	.026
	streets*point size	within	.20

The two factors that most influence error rate are subject age and the number of streets shown on the map. (See Figure 27.) Older subjects made almost 4 times more errors than younger subjects (81 versus 21), and increasing the number of streets shown on the map from 12 to 24 increased the average number of errors by 49 percent (from 41 to 61).

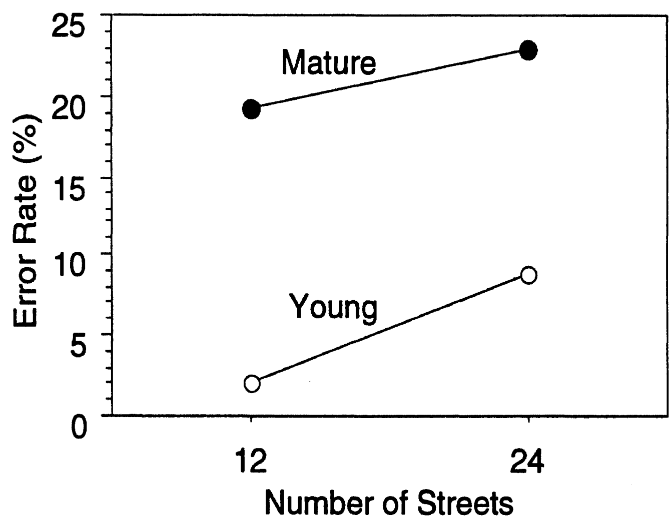


Figure 27. Task 3: Effects of age and number of streets on error rate.

Response location was also found to be significant; however, its high level of significance is likely an artifact of the "not there" condition. When the correct response was "not there," the error rate was near 0 percent which is significantly less than the 15.4 percent average error rate for the other locations (ahead, behind, left, and right). As shown in Figure 28, the error rates for young subjects did not vary as a function of target street location, but mature subjects had increasing difficulty correctly locating the street when the target street was behind or off to the side.

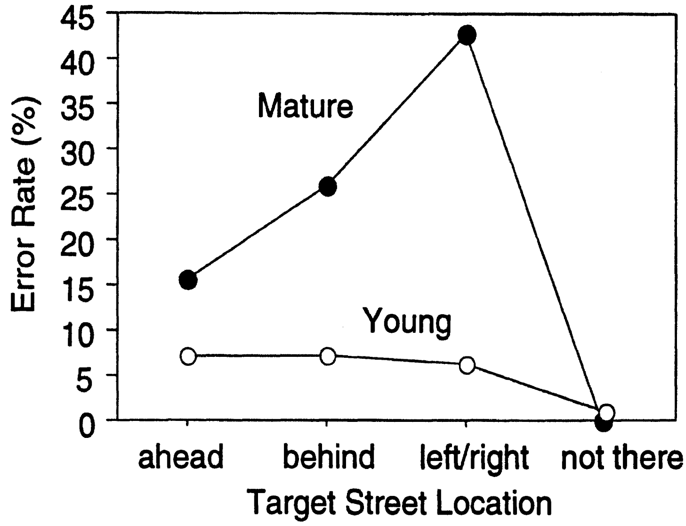


Figure 28. Task 3: Effects of target street location on error rate.

Point size and several of its interactions were found to significantly affect error rate; however, this is also likely an artifact created by excessive errors on a particular slide. For slide 6 (target street "Martin," shown in 12 point), the error rate was 56 percent. All mature subjects failed to find the name on the map. Removal of the "Martin" trial eliminated the observed differences in error rate due to point size.

Response Time

The response times for Task 3 ranged from 1000 to 19580 ms with a mean of 5210 ms (standard deviation = 3225 ms). Figure 29 shows the distribution and the cumulative distribution of response times measured during this task.

The response time analysis used a repeated measures ANOVA model. Table 12 summarizes the main effects and significant interactions examined in Task 3. Higher order interactions were computed but not reported in the Task 3 ANOVA table. (See Appendix N.)

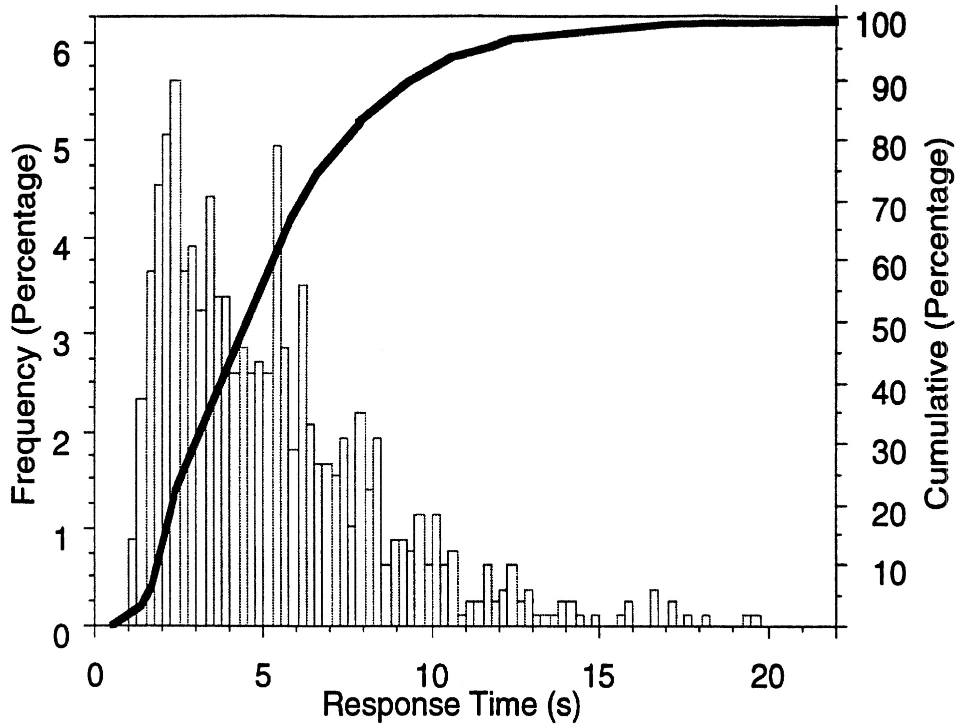


Figure 29. Task 3: Distribution of response times.

Table 12. Task 3: Response time main effects and significant interactions summary.

Effect Category	Factor	Effect Type (between, within, mixed)	P-Value
Subject	age	between	.0018
	gender	between	.78
	age*gender	between	.31
Context	road	between	.063
	time sequence	between	.60
	time of day	within	.068
	time*time sequence	mixed	.72
	response location	within	<.001
Map Design	number of streets	within	<.001
	streets*age	mixed	.035
	streets*location	within	.0033
	point size	within	.16

Subject Effects (Age and Gender)

Age was the only statistically significant subject effect. The difference between mature subjects (mean 6710 ms) and young subjects (mean 3710 ms) was 3000 ms (an increase of 81 percent). Gender was not significant and neither was an age-by-gender interaction with a mean absolute difference between men and women of only 120 ms. Variability increased with the subject age (2030 ms for young subjects, 3490 ms for mature subjects). Figure 30 shows the effects of age and gender.

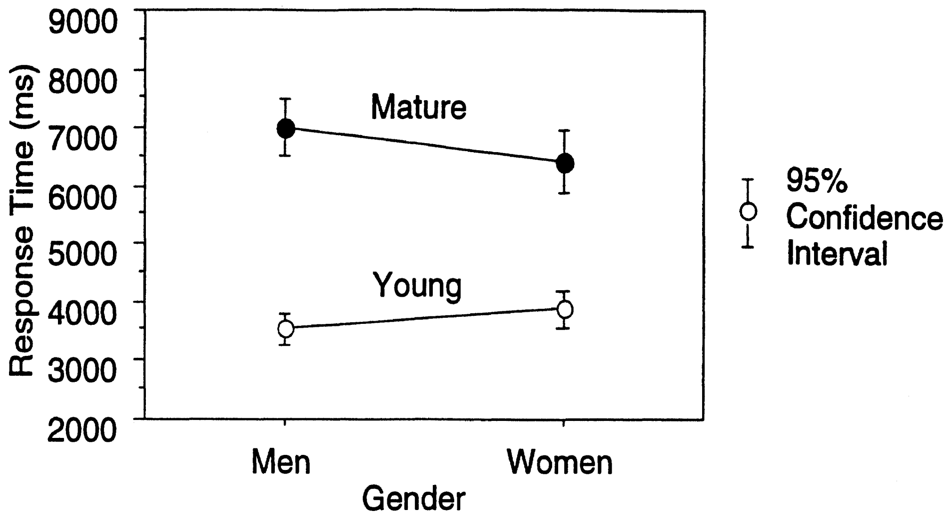


Figure 30. Task 3: Effects of age and gender on response time.

Context Effects (Road, Time of Day, and Response Location)

Overall, there were no significant effects for road, time of day, block, or the time by block interaction. The mean response time difference between roads was 1040 ms (see Appendix G for further discussion on the differences found between roads); and the response time decreased by an average of only 80 ms (1.5 percent) between the first and second sessions indicating that no strong learning effect was present for this task. However, response times showed 10.5 percent increase (520 ms) from day sessions to night sessions as shown in Figure 31.

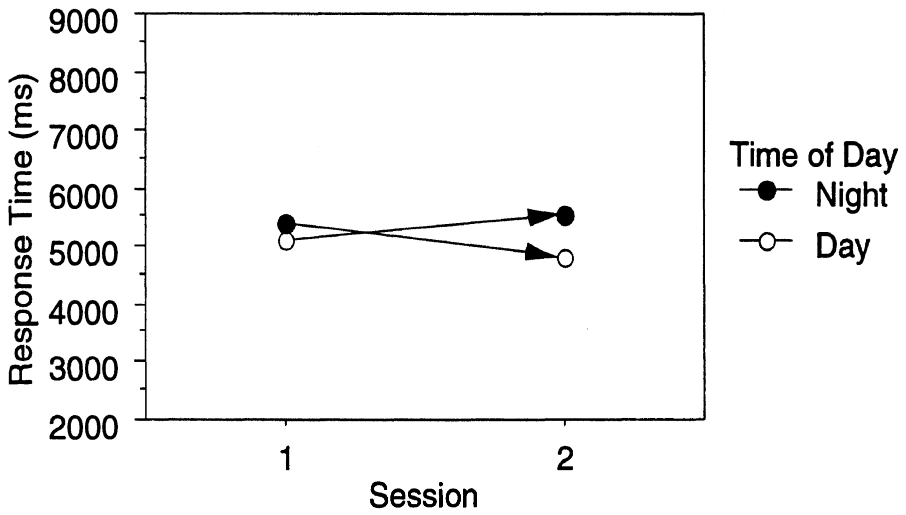


Figure 31. Task 3: Effects of time of day and session on response time.

The response location was also significant. Four categories of response location were used to identify the location of the target street: "ahead, behind, left/right, or not there." Note that left and right were pooled into one response category because earlier work found no significant difference in response times. Figure 32 shows the average response time for target streets found in each location without errors. There was little difference between the response times for "behind", "left" or "right"; however, when the target street was "ahead", the subjects found the name 24 percent faster. Finally, the response of "not there," signifying that the subject could not find the name on the map, increased the response times proportional to the average response time for the subject's age and map's design characteristics. The "not there" response was thus modeled as a multiplicitive effect increasing the response time by a factor of approximately 1.70.

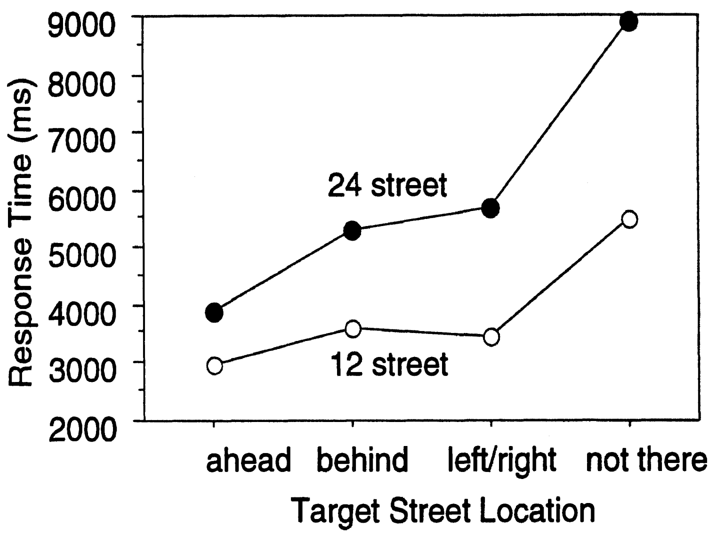


Figure 32. Task 3: Effect of target street location on response time.

The response location pattern of results was consistent with the search pattern or strategy described during the post test survey. All subjects reported that their search started near the top of the screen (usually upper left, which explains why ahead locations were found faster) and moved around the display either clockwise or counterclockwise depending on the subject. With half of the subjects searching clockwise and the other half counterclockwise, the average response times for right and left should equal that of behind.

Map Design Effects (Number of Streets and Point Size)

The number of streets shown on the map was significant; however, the label point size was not. The point size effect was only 5.9 percent (300 ms) less for 12 point compared with 10- and 14-point (after errors had been filtered out). The lack of a significant point size effect in this task may be due to the strategies used to complete the task. Many subjects reported that they did not read the entire name while searching. They looked for only names near the approximate length of the target name and then matched only the first few letters before responding.

As the number of streets increased from 12 to 24, the average response time increased by 55 percent (2250 ms). Additionally, the number of streets by age interaction was found to be significant with older drivers having relatively more difficulty with 24-street maps than younger subjects. (See Figure 33.)

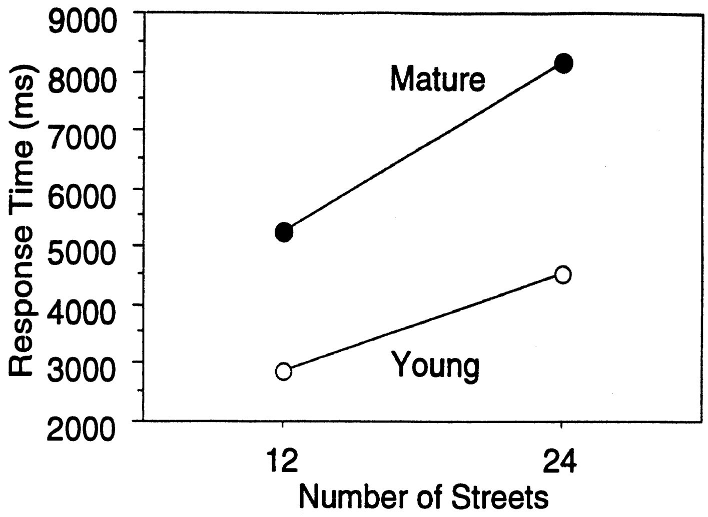


Figure 33. Task 3: Effects of age and number of streets on response time.

Task 3 Response Time Prediction Model

The basic model for predicting the Task 3 response time contains 5 factors: age, time of day, the number of streets shown, the target location, and the search result. The first 3 terms in the model represent the linear effects of age, time of day, and the number of streets shown. The next term represents the interaction between the number of streets shown and the subject's age. The final 2 terms in the model show the effects of the target street location and the search result.

Response Time = [1630 + 1235*(A) + 380*(T) + 136*(S) + 27*(A)*(SL) + 475*(L)]*(SR)

where

$$A = \text{Age} \begin{cases} -1 \text{ for young subjects} \\ +1 \text{ for mature subjects} \end{cases}$$

$$T = \text{Time of day} \begin{cases} -1 \text{ for day} \\ +1 \text{ for night} \end{cases}$$

$$S = \text{Number of streets } (S \geq 1)$$

$$SL = \text{Street Level} \begin{cases} -1 * (24 - S) \text{ for } S \leq 12 \\ +1 * (S - 12) \text{ for } S > 12 \end{cases}$$

$$L = \text{Target Location} \begin{cases} -1 \text{ for ahead} \\ 0 \text{ for not there} \\ +1 \text{ for behind, left or right} \end{cases}$$

$$SR = \text{Search Result} \begin{cases} 1 \text{ if target is found} \\ 1.70 \text{ if target is not found} \end{cases}$$

The model predictions were plotted against the actual response time in Figure 34 with an uncorrected R^2 of 87 percent for all 768 Task 3 trials.

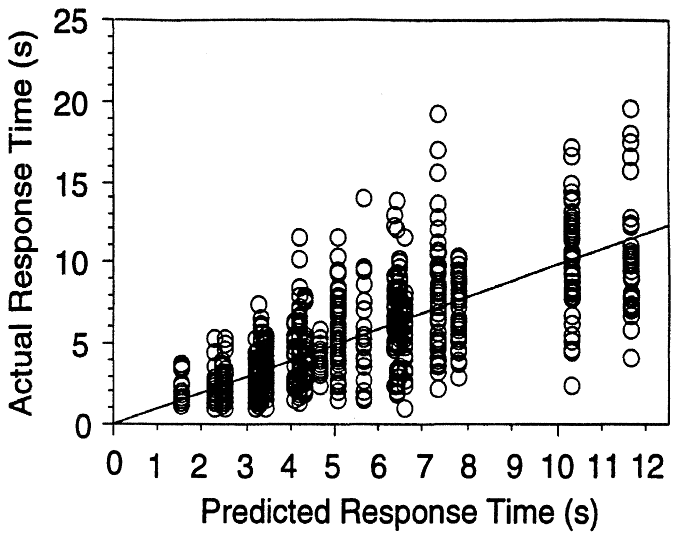


Figure 34. Task 3: Predicted response time vs. actual response time.

Driving Performance

Lane excursions occurred during 5 percent (41) of the trials while unintentional speed decreases occurred during 6 percent (46) of the trials. They occurred together on only six trials (versus only two if they were truly independent), suggesting little or no dependency. As in Task 2, driving performance varied greatly between subjects. (See Table 13.) Generally, mature subjects committed twice as many driving errors in this task as younger subjects, and women committed 1.5 times as many driving errors as did men.

Table 13. Task 3: Number of driving performance errors per subject.

Age	Gender	Subject	Response Time (ms)	Lane Excursions	Speed Decreases
Young	Male	1	3420	0	0
		2	3390	0	0
		3	4270	0	2
		4	3060	0	0
	Female	1	5130	3	2
		2	3500	3	1
		3	3780	0	2
		4	3140	1	0
Mature	Male	1	7310	3	9
		2	7320	0	9
		3	5450	0	2
		4	7950	9	10
	Female	1	8470	8	14
		2	7320	1	4
		3	4800	6	0
		4	5090	6	0

Similar to Task 2, for a single glance to the display, 70 percent of the driving errors occurred when the response time exceeded 2.5 seconds. For multiple glances to the display, 92 percent of the driving errors occurred when the response time exceeded 5 seconds. (See Figure 35.) Additionally, the probability of a driving error increased as the response time increased, although the exact magnitude of the increase was again confounded with the sample size differences between each response-time category (see Figure 36).

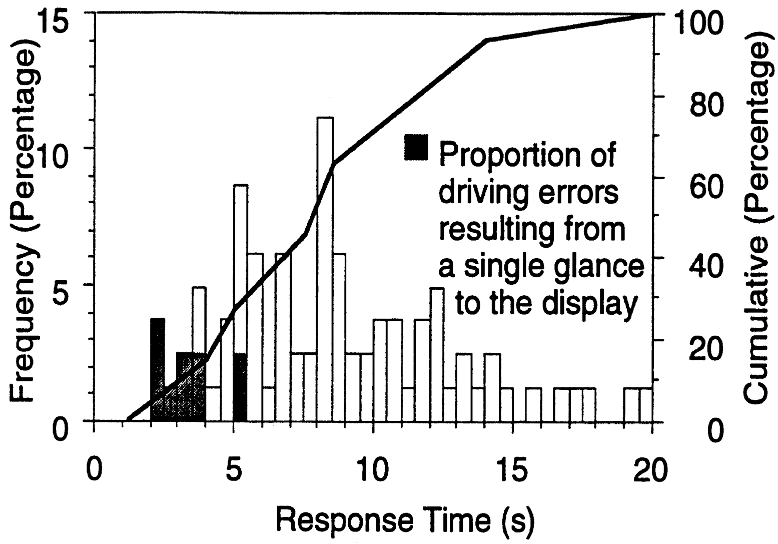


Figure 35. Task 3: Distribution of trial response times resulting in a driving error.

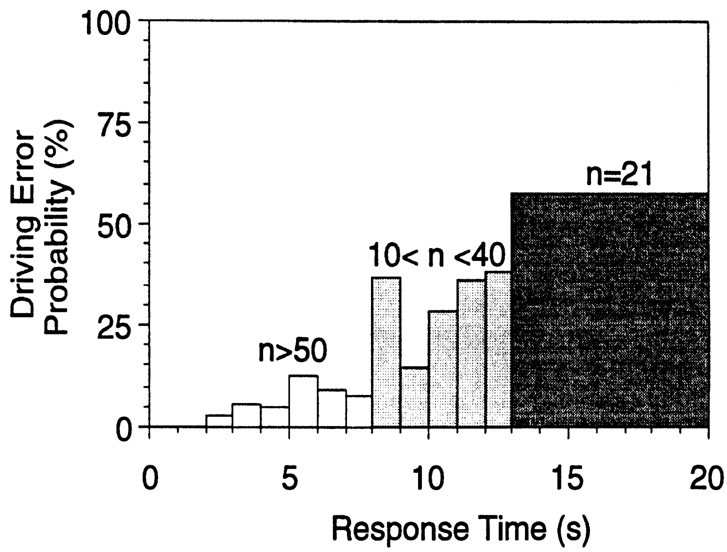


Figure 36. Task 3: Probability of a driving error given response time.

Given that driving performance was correlated with longer response times, it was also correlated with factors that increased response time. It therefore stands to reason that driving performance was not well correlated with time of day, session, or label point size. It was correlated with the number of streets and the response. (See Figure 37.) As the number of streets increased from 12 to 24 the number of driving performance errors doubled (from 27 to 60). Over half of the driving errors occurred on trials where the subject's response was "not there."

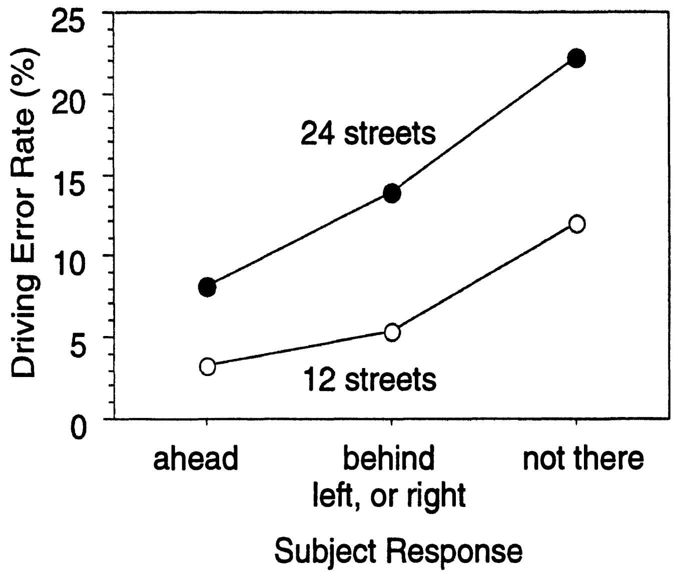


Figure 37. Task 3: Driving error rate as a function of the number of streets on the map and map response.

Finally, driving performance errors were not correlated with task errors (incorrect responses). Approximately 80 percent of the driving errors occurred on trials where the subject eventually responded with the correct answer. The remaining 20 percent of the driving errors occurred when the subject responded incorrectly with "not there."

Subjective Task Ratings

After each task the subjects were asked to rate the difficulty of the task on a scale from 1 to 5 using the descriptions found in Table 14. The average rating, response time, and number of glances to the display per task are listed in Table 15. The task ratings reported ranged from 1 to 4. The use of the word "unsafe" appeared to skew the ratings upwards since the subjects were instructed at the beginning of the experiment to stop the task if they felt unsafe at any time. On average, younger subjects rated the tasks as less difficult (by .25 points) than mature subjects. Men rated the tasks as less difficult than women by .20 points. All subjects rated the tasks during the second experimental session as less difficult by an average of .25 points. There were no ratings differences between day and night or between the two experimental roads.

Table 14. Task rating scale anchors.

Rating	How much did the task interfere with driving and how safe did you feel?
1	No interference with driving. I felt very safe.
2	Some interference with driving, but I still felt safe.
3	Some interference with driving, but sometimes I started to feel unsafe.
4	Much interference with driving, I felt unsafe.
5	Extreme interference with driving, I felt very unsafe.

Table 15. Average rating, response time and glances per task.

Task	Average rating	Average response time (ms)	Average number of glances
1	1.34	1790	1.03
2	2.34	3370	1.41
3	2.56	5210	2.25

There appeared to be a correlation between the average response time and the average rating. (See Figure 38.) To answer the question of when drivers begin to feel unsafe while reading maps, the boundary between when drivers felt safe and when they felt unsafe was placed at the rating of 2.5, which corresponded to a response time of 5 seconds. It should be noted that the task mean response time alone was not a sensitive predictor of the rating (or the driver's capabilities) because of the confounds between the response time and the number of glances used to complete the task. This was evident by the fact that across all subjects, Task 2 (where most drivers preferred to try to complete the task in a single glance) was rated almost as high as Task 3 (where most drivers preferred a multiple glance strategy) even though the mean response time for Task 2 was almost 2 seconds less than that of Task 3.

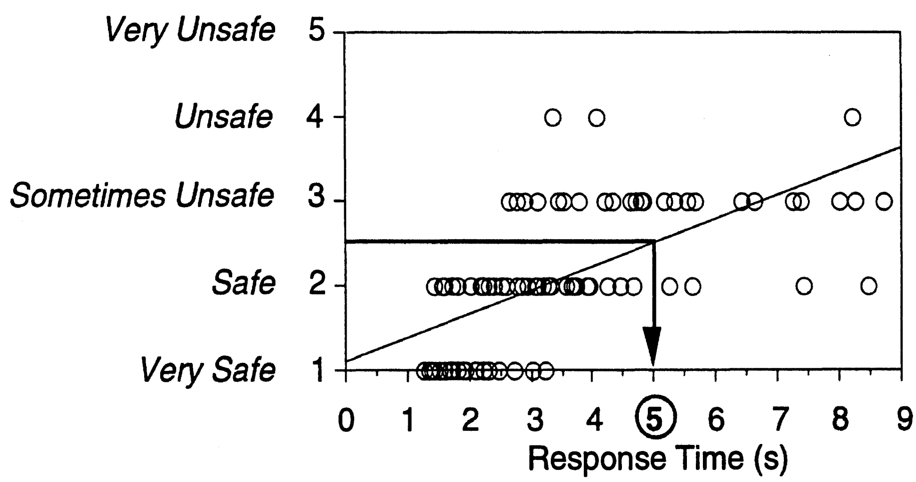


Figure 38. Response time as a predictor of rating.

Driver Eye Movements

For each trial of each task, the number of glances between the road and the display were counted. The number of glances per trial ranged from 1 to 10. Figure 39 shows the relationship between the average number of glances and the average response time per task for each subject. A simple regression showed that for each response time increment of 2.35 seconds, the subjects preferred to add an eye glance to the road.

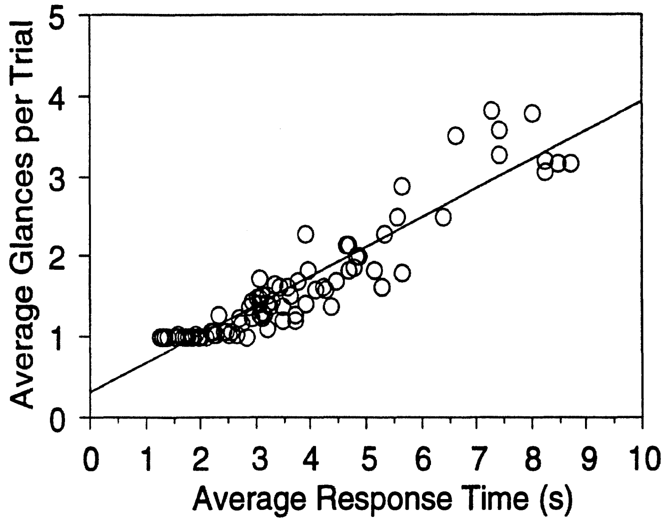


Figure 39. Number of glances as a function of response time.

Figure 40 shows a more detailed distribution of response times per number of display glances. Any task requiring approximately 2 seconds or less to complete required only one glance to the display, and the average response time for a single display glance was approximately 2.2 seconds. In contrast, the maximum response time for only one display glance was 6.4 seconds, and the 95 percentile was just under 4 seconds.

As tasks began to require multiple glances, the range of response times per glance increased. For 2 glances, the response times ranged from 1.5 seconds to almost 9 seconds (with a mean of 4.7 seconds); however, only the sums of the glances are reported, not the individual glance durations.

This simple analysis gives a rough estimate of the expected range of times for which drivers are comfortable looking away from the road. It should be noted that the response times used in this analysis are not to be confused with the actual eyes-away-from-the-road time. Subjects may have delayed looking at the display (due to traffic) when the map appeared and timer started, and subjects usually returned their eyes to the road before the actual response was made. Additionally, multiple glances do not distinguish between eyes-on-the-display and eyes-on-the-road time.

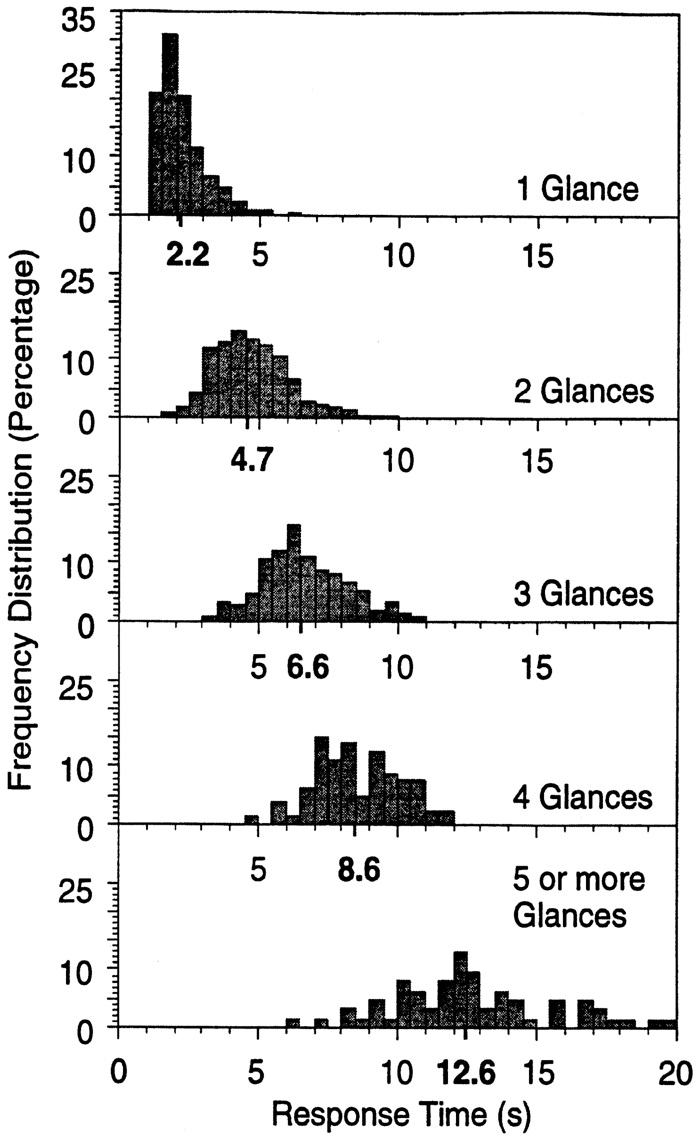


Figure 40. Frequency distribution of response times per number of glances.

CONCLUSIONS

How long does it take on average to read an electronic map?

Three tasks ranging in difficulty were examined in this experiment. Task 1 (What street are you on?) was relatively easy. The response times for this task ranged from 1 to 2.5 seconds and in most cases required only a single glance to the display. Task 2 (What is the nth cross street?) required a more difficult structured search of the map. Response times for this task increased as the number of the target cross street increased. The average response times ranged from 1.6 to 5.2 seconds requiring 1.5 glances (on average) to the display. Task 3 (Where is the target street?) required an even more difficult unstructured search of the map. The response time increased in proportion to the number of items to be searched with typical response times ranging from 2 to 8.4 seconds and requiring, on average, 2.25 glances to the display.

When do the drivers feel that map reading is unsafe while driving?

During expressway driving, the natural tendency of drivers was to limit their visual interaction with the system to under 3 seconds per glance. According to the data on driving errors for a single glance to the display, the number of lane excursions and losses of speed would be reduced by 80 percent if the task required no more than 2 seconds of visual attention to complete (not including transition times).

Although the driver preference data collected was biased by the anchors in the rating scale, the driver preferences should also be considered. Since the rating scale anchored the drivers' impressions of "safe" at 2 and "unsafe" at 3, a rating of 2.5 could be considered a design threshold not to be exceeded. A rating of 2.5 in this experiment corresponded to an average response time of about 5 seconds, suggesting that drivers become uncomfortable when their interactions with the system require more than two glances (since drivers limited each glance to under 3 seconds). The driving-error data also supports this conclusion since 86 percent of the multiple-glance driving errors occurred when the response time was greater than 5 seconds.

Given the drivers' tendencies and preferences as described above, two map design criteria can be recommended that would reduce the overall number of driving errors by 85 percent. Tasks requiring the driver's visual attention while the vehicle is in motion should be designed such that they can be completed using, first, display glances of no more than 2 seconds and, second, no more than a total of 2 display glances.

How did age and gender affect the map reading time?

The only subject effect consistently significant across all tasks was the driver's age. The response time differences between younger and mature drivers increased as the task difficulty increased. For a relatively easy task such as Task 1, the reading times were 40 percent greater for older subjects, and for a more difficult search task, Task 3, the response times for older subjects were up to 80 percent longer. The age effect also increased within the task as the within task difficulty increased. Additionally, mature subjects were more sensitive to many of the variables tested (point size in Task 1 and target street location in Task 3) than were younger subjects.

How many streets should be displayed on the map?

Across all tasks, increasing the number of streets displayed increased the response times. For simple tasks the increase was slight (about 7 ms per street); but for more difficult tasks, such as an unstructured search, the response times increased by 140 ms per street. However, one issue that was not addressed in this experiment was the cost of displaying additional unlabeled streets. During the unstructured search, Task 3, the streets effect was confounded with the number of search items or names on the map. Since Task 3 required the driver to search through all the names, the addition of unlabeled streets should not affect the response time as much as the addition of labeled streets. Limiting the number of labeled streets displayed to 12 or less is the recommended strategy to keep the map reading times under 5 seconds.

How big should the text be?

This experiment tested 10-, 12- and 14-point text labels. (Note that point size refers to the character height measured on the display.) Younger drivers were not sensitive to the differences in text size in this range, and as the task difficulty and average response times increased, the relative effect of point size became masked by the magnitude of the other factors' effects. For mature drivers, the 10-point text generally produced the slowest reading times and the most complaints. Mature subjects performed up to 200 ms (10 percent of a single glance) better when reading 12- and 14-point text. Text sizes 10 point or smaller should not be used for an in-vehicle navigation system. The preferred text size for street labels (as well as menus and informational messages) is 14 point. However, bigger text is not always better.

As the text size and number of streets presented on the display increase, the overall map clutter increases as well. As shown in this experiment, even mild clutter can increase the map reading time by 10 percent and increase the errors as the text starts to mask streets or intersections. Using a 5-inch diagonal screen as baseline, if the number of labeled streets increases beyond 12, then either the text label size should be reduced to 12 point or the screen size should be increased to reduce the effects of clutter. Although increasing the screen size may help reduce the effects of clutter, map search times (tested in Task 3) were primarily related to the number of streets on the map. Increasing the number of streets displayed on the map, even when accompanied by an increase in screen size, will still cause an increase in response time.

How does the ambient lighting (time of day) affect map reading?

For the easy single glance tasks, such as Task 1, the time of day had little overall effect on the response times. However, for more difficult multiple glance tasks, such as Task 3, nighttime responses were about 500 ms longer than daytime responses, and the subjects subjectively rated the night condition as more difficult. One possible explanation for the increased night response times was that driving at night was more difficult due to degraded visibility. During night driving, the interglance interval might have been longer because the drivers needed to fixate on the road longer to maintain control of the vehicle. A second possibility was the differences in the display's brightness and contrast at night. Even though drivers were free to select the desired brightness and contrast for the in-vehicle display at night, drivers may not have selected an optimal setting.

Two interesting lessons were learned from the night sessions. First, although time of day had little effect on the response times for simple tasks, learning the tasks appeared more difficult at night. In all tasks, the learning effect between experimental sessions was amplified for those driving the night session first. Second, the issues of color selection and brightness are important at night. The pilot tests used black text on a white background to maximize contrast, but all drivers agreed that this combination was far too bright and distracting for night driving. For the actual experiment, the white background was replaced with a grey (decreasing the brightness but reducing the contrast); however, user preferences on this issue varied greatly with some requesting more luminance and some requesting much less. Clearly, the issues of color, luminance, and contrast preferences need to be addressed in further research.

How can response time be predicted given the map design?

The response-time regression equations for the three tasks are summarized in Table 16. These equations can be used to predict the driver's response time given the task and the map-design characteristics.

Table 16. Summary of response time prediction equations.

Response Time (ms)		Predictive Equation
Task 1	=	$6710 + 325*(A) + 6.67*(S) + 33.75*(P)^2 - 832.50*(P) + 9.58*(C)$
Task 2	=	$1210 + 575*(A) + 370*(X) + 40.83*(S) + 8.08*(P-12)*(SL) + 40.83*(S-12)*[\text{MINIMUM}(1,X-2)]$
Task 3	=	$[1630 + 1235*(A) + 380*(T) + 136*(S) + 27*(A)*(SL) + 475*(L)]*(SR)$

Factor Definitions

$A = \text{Age} \begin{cases} -1 \text{ for young subjects} \\ +1 \text{ for mature subjects} \end{cases}$

$T = \text{Time of day} \begin{cases} -1 \text{ for day} \\ +1 \text{ for night} \end{cases}$

S = Number of streets ($S \geq 1$)

P = Label point size ($10 \leq P \leq 14$)

X = Target Cross Street ($X \geq 1$)

$L = \text{Target Location} \begin{cases} -1 \text{ for ahead} \\ 0 \text{ for not there} \\ +1 \text{ for behind, left or right} \end{cases}$

$SL = \text{Street Level} \begin{cases} -1*(24-S) \text{ for } S \leq 12 \\ +1*(S-12) \text{ for } S > 12 \end{cases}$

$SR = \text{Search Result} \begin{cases} 1 \text{ if target is found} \\ 1.70 \text{ if target is not found} \end{cases}$

$C = \text{Clutter} \begin{cases} 0 \text{ for point size} \leq 12 \\ (P-12)(S-12.52) \text{ for point size} > 12 \end{cases}$

SIMULATOR VALIDATION

Validation Method

A second goal of this experiment was to validate the use of a driving simulator to study secondary response-time tasks. To allow for a comparison between the simulator and the on-the-road experiment, the two experiments contained a common subset of map-design conditions. Both the simulated and the real roads used were relatively easy to drive with no sharp curves and low traffic volumes, but no effort was made to exactly match their difficulty. The comparison looked at two tasks, Task 1 and Task 3. Task 1 represents a relatively easy task with response times ranging from 1 to 3 seconds and in most cases requiring only a single glance from the road to the display. Task 3, in contrast, represents a more difficult task with response times ranging from 1 to 20 seconds and in most cases requiring multiple glances between the road and the display. Due to the complexity of analysis and the low sample size (few trials had overlapping conditions between experiments), Task 2 was not validated. The simulator experiment used 20 subjects equally blocked for age and gender, while the on-the-road experiment used only 16 subjects (again equally blocked for age and gender). Each subject only participated in one experiment.

In Task 1, the overlap between the two experiments yielded 12 unique simulator trials per subject. These trials were compacted to 6 trials per subject by averaging over response to form a full factorial using 2 levels of streets (12 and 24) and three levels of point size (10, 12, and 14). The on-the-road experiment used 48 trials per subject, which were collapsed to 6 trials per subject by averaging over time of day and map template. None of the factors averaged over were statistically significant in the experiment's original analyses. It should also be noted that the simulator data was collected in 1 block of 72 trials (from which the 12 overlapping trials were taken), whereas the on-the-road data was collected from 2 blocks (separated by several days) of 24 trials. No significant learning effects were reported for this task in either experiment.

Task 3 contained 24 overlapping trial conditions per subject. For the simulator, the 24 trials came from the full factorial of 2 levels of streets (12 and 24), three levels of point size (10, 12, and 14), and 4 responses (ahead, behind, left/right, and not there). The on-the-road experiment used 48 trials per subject which was collapsed to 24 trials per subject by averaging over time of day. Although there was a slight time-of-day effect for Task 3 in this experiment, the ambient lighting levels in the simulator mimic those of dusk, which is neither day nor night as tested in the on-the-road experiment. It should also be noted that the simulator data was collected in 1 block of 108 trials whereas the on-the-road data was again collected from 2 blocks of 24 trials. As in Task 1, no significant learning effects were reported for Task 3 in either experiment.

Validation Results

Task 1: What Street Are You On?

The error rate was 2.1 percent in the simulator experiment and 1.8 percent in the on-the-road experiment showing essentially no difference between experiments. The combined response times for Task 1 ranged from 930 to 4440 ms with a mean of 1710 ms (standard deviation = 510 ms). Figure 41 shows the distribution and the cumulative distribution of response times for each experiment.

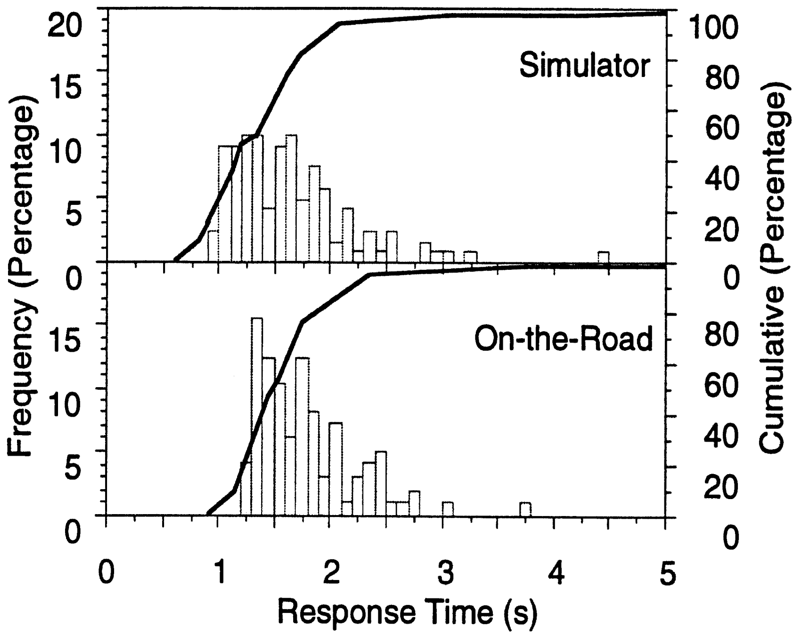


Figure 41. Comparison of response time distributions for Task 1.

An initial correlation between the two experiments (averaging across subjects over age and gender) resulted in an $R^2 = .64$ (see Figure 42). The response times appeared randomly distributed between experiments (i.e., the simulator response times are neither consistently higher or lower than the on-the-road response times).

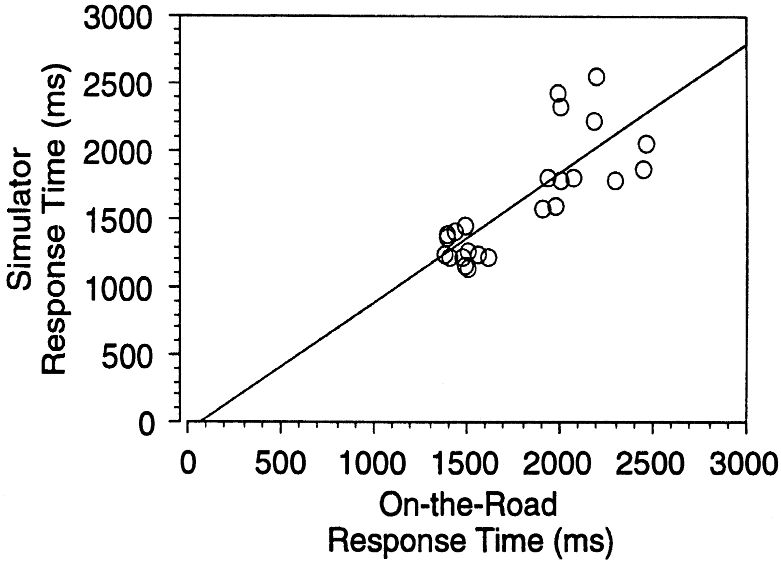


Figure 42. Task 1 correlation between experiments.

The response time analysis used a repeated measures ANOVA model. Table 17 summarizes the main effects and significant two-factor interactions examined in

Task 1. Each significant effect or interaction is followed by an interaction with experiment to determine whether the nature of the effect or interaction changed between experiments. The ANOVA table for Task 1 (not including higher order interactions) appears in Appendix O.

Table 17. Task 1: Response time main effects summary.

Classification of Effect	Factor	Effect Type (between, within, mixed)	P-Value
Context	experiment	between	.08
Subject	age	between	<.001
	age*experiment	between	.74
	gender	between	.21
	age*gender	between	.13
Map Design	number of streets	within	.17
	streets*experiment	mixed	.62
	point size	within	.05
	point size*experiment	mixed	.0041
	point size*age	mixed	.02
	point size*age*exp	mixed	.57
	streets*point size	within	.0082
	streets*point size*exp	mixed	.92

Context Effects

The average response time for the simulator trials was 1640 ms while the average response time for the on-the-road experiment was 1790 ms resulting in a 10 percent difference (150 ms) between experiments, which was not statistically significant. One explanation for the response time increase, which can be ruled out, is the display position. The simulator display required a combined horizontal and vertical eye movement of only 3 degrees of visual angle less than the display used in the on-the-road experiment. (See Appendix P for details on the display positions in each experiment.) Since both angles were above 30 degrees, both experiments required a head movement in conjunction with a saccadic eye movement, and an extra 3 degrees should only add 6 ms to the reaction time.

Subject Effects

The only subject effect that was significant in either experiment was the age effect. (See Figure 43.) Both gender effect and the age by gender interaction were not statistically significant. The observed age effects differed by only 55 ms between experiments which was not statistically significant. There were large individual differences observed between subjects. This is most noticeable in the mature female category of the simulator experiment where the response times ranged from 1475 ms (on par with the younger subjects) to 2120 ms (near the average of the mature males).

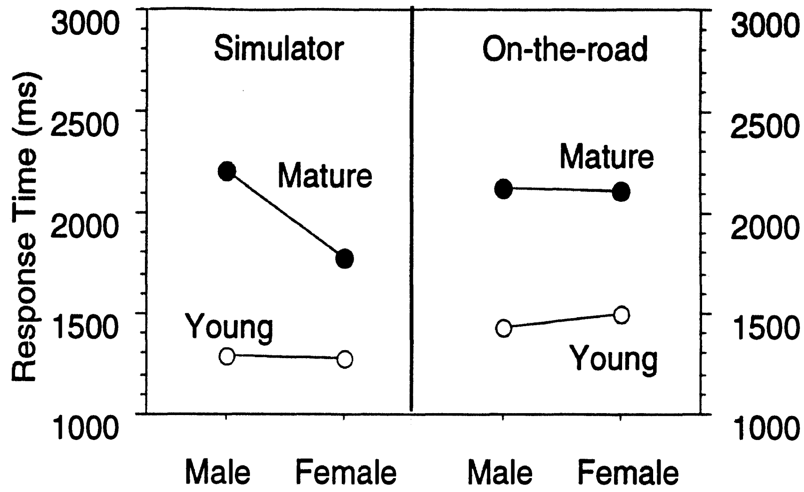


Figure 43. Task 1: Comparison of subject effects between experiments.

Map Design Effects

The number of streets shown on the map was not found to be significant in this analysis, which contradicts the findings of both experiments. This is probably due to the limited number of data points taken per subject. When each experiment was analyzed independently, both found a significant streets effect of approximately 80 ms (the difference between 12 and 24 streets). Additionally, both experiments independently concluded (though not statistically significantly) that the streets effect was slight less for younger subjects (30 to 40 ms) and slightly more for older subjects (120 to 130 ms).

The point-size effect and point-size-by-age interaction were both significant. The point size affected the older subjects more than it affected the younger subjects. Both the simulated and actual conditions observed this trend; however, the two studies differed as to which point size was better. The simulator found that 14 point was best while the on-the-road experiment found that 12 point was best overall. (See Figure 44.)

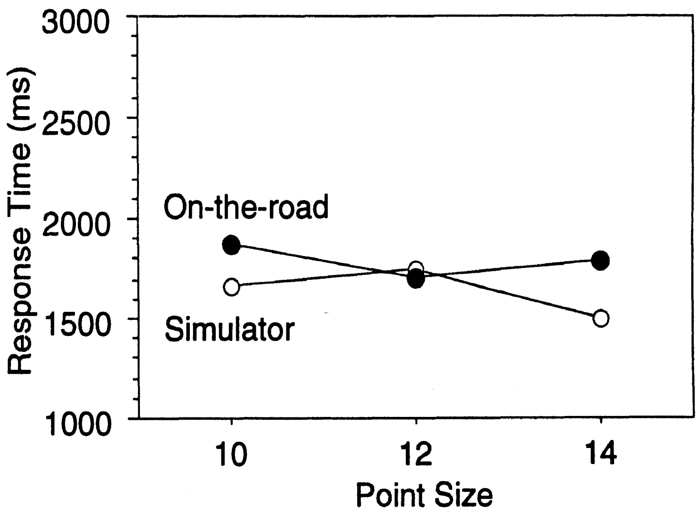


Figure 44. Task 1 point size effect differences between experiments.

The point-size-effect differences seen between experiments occurred due to two factors. First, the simulator data was based on only 12 select trials per subject, and the point size trends described above are not consistent with the conclusions drawn from the entire data set. The 12-point average response time is overestimated (by 150 ms) and the 10-point response time is underestimated (by over 200 ms). The general trend in the simulator experiment showed a decreasing response time as the point size increased from 10 to 14 point. Since this pattern was not mimicked in the data subset used in the simulator validation analysis, the lower simulator 10-point response times can be attributed to a skew that occurred when the data set was reduced.

Second, the experiments used two different projection methods and viewing distances. In the simulator, the maps were made into slides and projected onto a white screen near the center of the vehicle console while the on-the-road experiment made use of an active matrix LCD. Controlling for the point size only entailed keeping a constant character screen height Due to the display resolution limitations of each display type, the character stroke widths varied between point sizes and display types. Figure 45 shows a better correlation between experiments after correcting for the stroke-width visual angle.

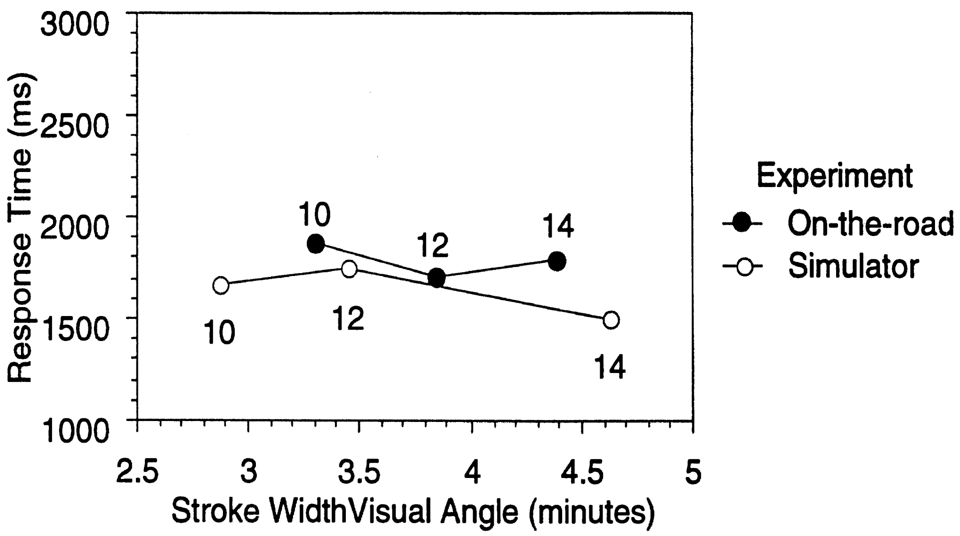


Figure 45. Task 1 point-size differences as a function of stroke-width visual angle.

A final point-size difference between the experiments was the lack of a streets-by-point-size interaction in the simulator experiment. In the on-the-road experiment the use of 14 point with a high level of streets produced a clutter effect which increased the response times for 14-point text. The clutter effect was not consistently seen in the simulator experiment (although a slight clutter effect was observed during the simulator study in Task 4, which was a variant of the Task 1). The clutter effect may be more pronounced in the on-the-road experiment because the LCD resolution was less than that of the slide projector.

Task 3: Where Is the Target Street?

The overall task error rate was 13.2 percent with no difference between the simulator and the on-the-road experiment. Similar trends in error rate were observed in the two experiments. Error rate increased as the subjects' age increased and as the number of streets on the map increased. Additionally, both experiments observed that the error rate for target streets located to either the left or right of the vehicle was 9 to 10 percent greater than for target streets located ahead or behind the vehicle. In both experiments few subjects responded incorrectly when the target street was not present on the map.

The combined response times for Task 3 ranged from approximately 1 to 21 seconds with a mean of 5630 ms (standard deviation = 3270 ms). Figure 46 shows the distribution and the cumulative distribution of response times for each experiment.

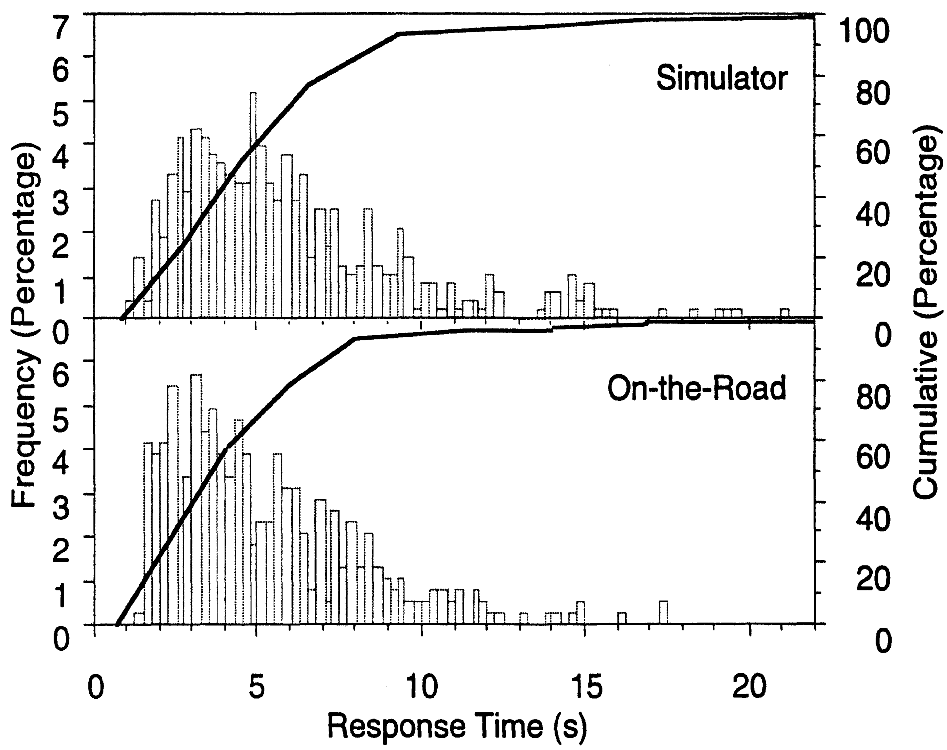


Figure 46. Comparison of response time distributions for Task 3.

An initial correlation between the two experiments (averaging across subjects over age and gender) resulted in an $R^2 = .66$ (see Figure 47). The response times appeared to be randomly distributed between experiments when the response times were under 8 seconds; however, for response times over 8 seconds, several of the simulator's estimates were extremely high.

The response-time analysis used a repeated measures ANOVA model. Table 18 summarizes the main effects and significant two-factor interactions examined in Task 3. Each significant effect or interaction is followed by an interaction with experiment to determine whether the nature of the effect or interaction changed between experiments. The ANOVA table for Task 3 (not including higher order interactions) appears in Appendix Q.

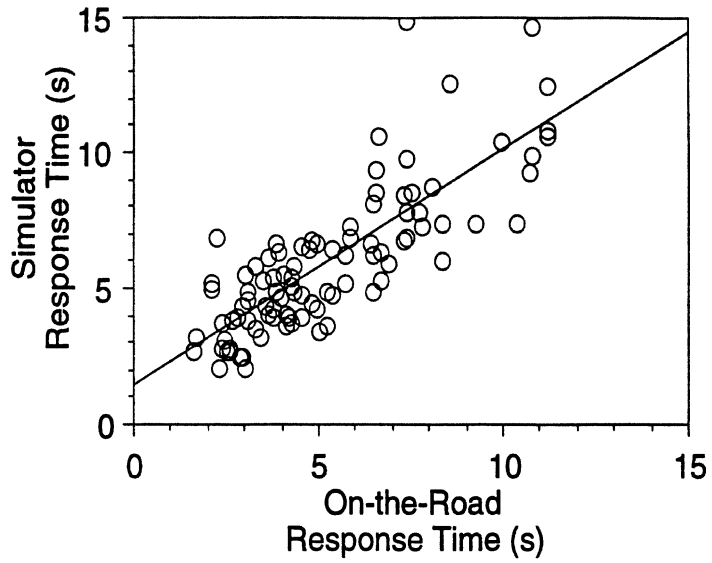


Figure 47. Task 1 correlation between experiments.

Table 18. Task 3: Response time main effects summary.

Classification of Effect	Factor	Effect Type (between, within, mixed)	P-Value
Context	experiment	between	.07
	response location	within	<.001
	location*experiment	mixed	.43
	location*age	mixed	.01
	location*age*exp	mixed	.44
	location*streets	within	<.001
	location*streets*exp	mixed	.07
Subject	age	between	<.001
	age*experiment	between	.88
	gender	between	.19
	age*gender	between	.06
Map Design	number of streets	within	<.001
	streets*experiment	mixed	.13
	streets*age	mixed	.0035
	streets*age*exp	mixed	.66
	point size	within	.01
	point size*experiment	mixed	<.001
	streets*point size	within	.89

Context Effects

The average response time for the simulator trials was 5960 ms, while the average response time for the on-the-road experiment was 5200 ms, resulting in a difference of 760 ms (13.5 percent) between experiments which was not statistically significant. This trend is the reverse of the one glance Task 1 finding where the simulator slightly underestimated the response times. One possible confound which may explain the Task 3 response time differences was the road difficulty. No effort was made to match the simulated road to either of the roads used in the on-the-road experiment. If the simulated road contained more curves or sharper curves than the actual test roads, a multiple glance task would be expected to require a combination of shorter display glances, more display glances, and/or longer road fixations between display glances, any of which would could cause longer overall response times.

In Task 3 an important context effect was the target streets location. Both experiments found that when the target street was located ahead of the vehicle icon, response times were approximately 20 percent faster. When the target street was not present on the map, the response times were 50 percent longer. The simulator estimated a 10 percent greater benefit for targets located ahead of the vehicle icon and a 25 percent less penalty for the target-not-found condition than the on-the-road experiment. However, these differences were not statistically significant.

The combined analysis also found the age-by-location and the streets-by-location interactions to be significant. The age-by-location interaction basically states that older subjects performed relatively better on the ahead location than the other locations. (See Figure 48.) The on-the-road experiment itself did not find a significant age by location interaction, but the data did support this same trend. The streets-by-location interaction shows that the "not there" response was likely not a linear effect, but a multiplicitive effect. The nature of the age-by-location and streets-by-location interactions did not significantly differ between experiments.

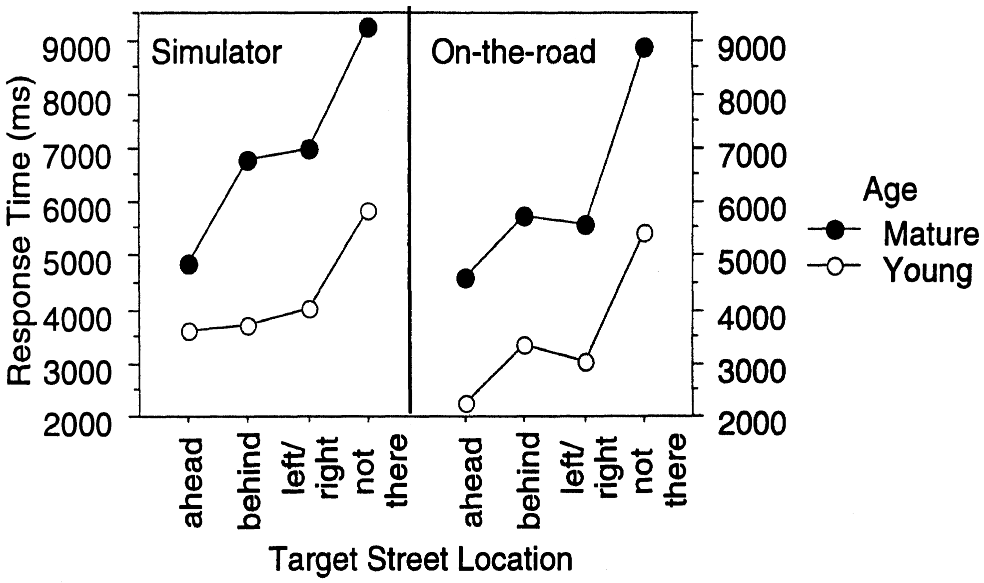


Figure 48. Task 3: Comparison of target-street-location effects between experiments.

Subject Effects

The only subject effect that was significant in either experiment was the age effect. (See Figure 49.) Both gender and the age by gender interaction were not statistically significant. The observed age effects differed by only 130 ms between experiments, which was not statistically significant.

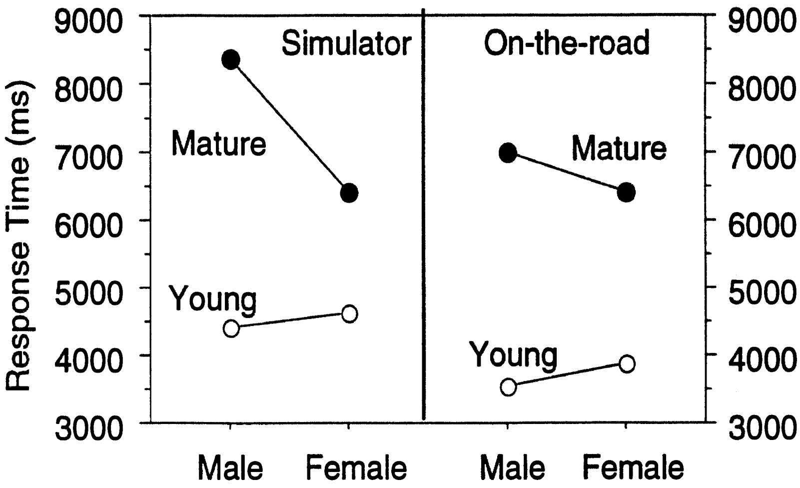


Figure 49. Task 3: Comparison of subject effects between experiments.

Map Design Effects

Both experiments found a significant streets effect. The response times increased approximately 210 ms per additional street shown on the map. The simulator experiment estimated the slope as slightly higher at 230 ms per each additional street, and the on-the-road experiment estimated the slope as slightly lower at 190 ms per each additional street. This difference was not statistically significant. In addition to the streets effect, both experiments observed a similar significant streets-by-age interaction. The older subjects had relatively more difficulty with 24-street maps than did younger subjects. (See Figure 50.)

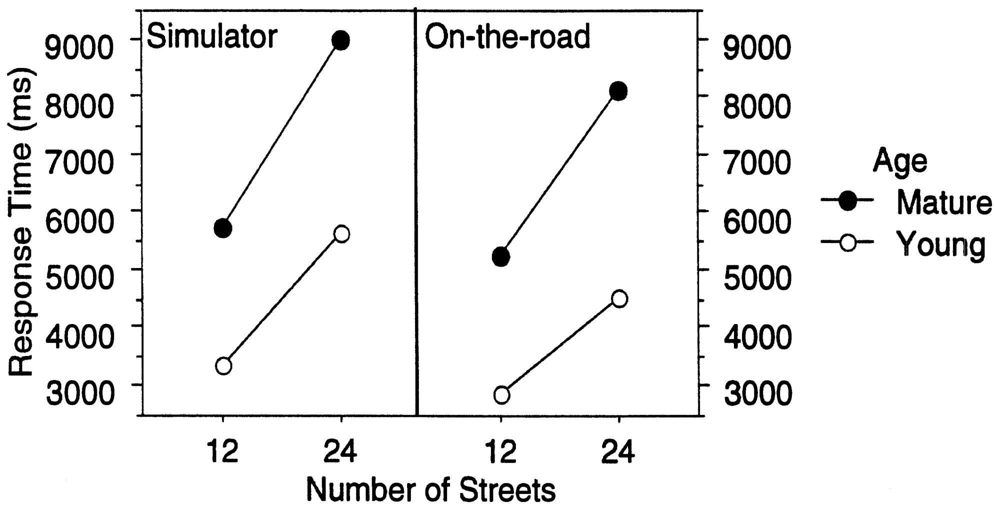


Figure 50. Task 3: Comparison of the by age interaction between experiments.

As in Task 1, the point-size effects seen in Task 3 differ between experiments. The simulator experiment observed a decrease in response time as the point size increased from 10 to 14 point while the on-the-road experiment observed no point-size effect. Figure 51 shows the point-size effects from each experiment as a function of the stroke-width visual angle. Although the stroke-width visual angle appeared to explain part of the point-size differences in Task 1, it does not appear to fully explain the differences observed between experiments in Task 3. However, as noted earlier, there was a sizable (760 ms) yet not-statistically-significant mean difference between the two experiments. In Figure 52, the response times have been adjusted to split the 760 ms difference between experiments showing, as in Task 1, that the stroke-width visual angle, not point size, may be the critical design variable and explain some of the observed differences between experiments.

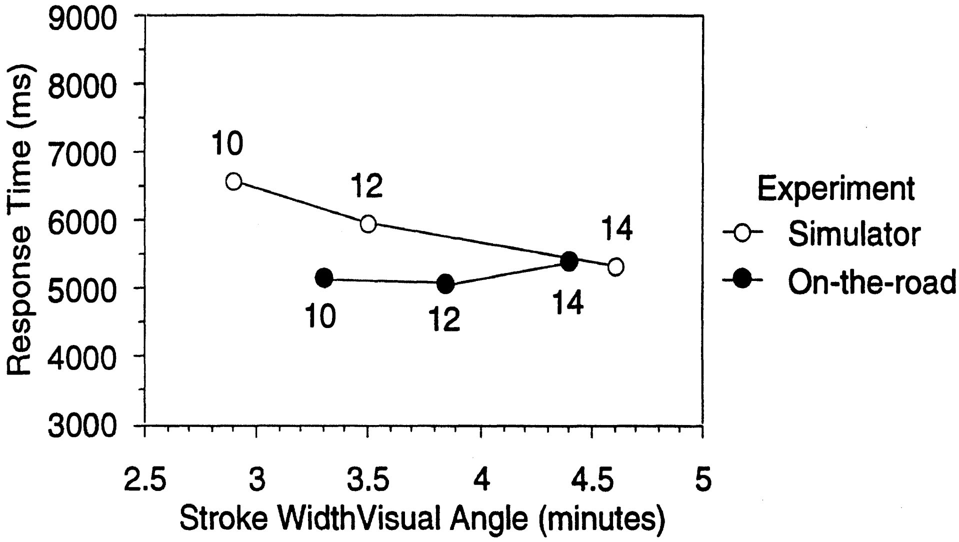


Figure 51. Task 3 point-size differences as a function of stroke-width visual angle.

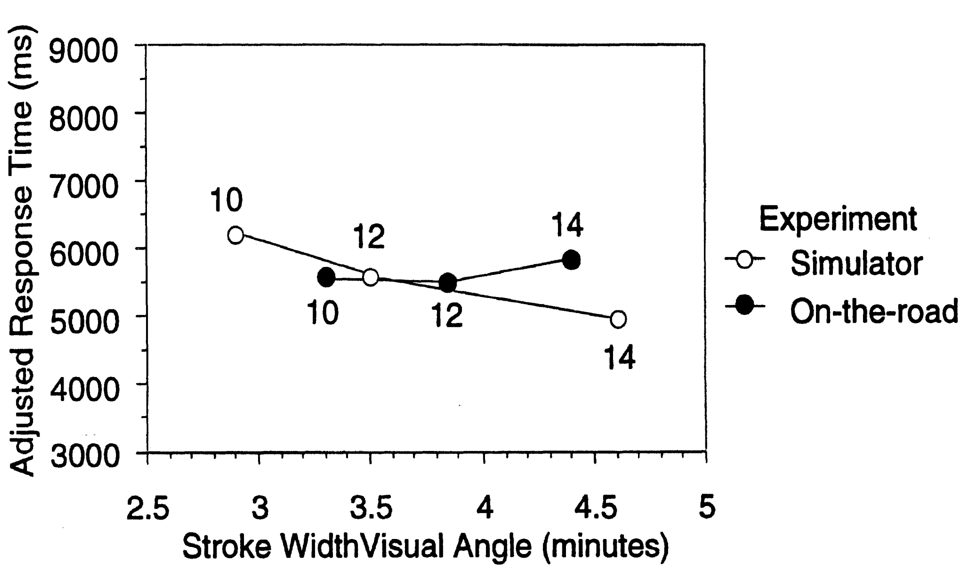


Figure 52. Task 3 point-size differences as a function of stroke-width visual angle adjusted to split the mean response time differences between experiments.

Simulator Validation Conclusions

A second accomplishment of this experiment was validating the use of a driving simulator to study secondary response-time tasks. The error rates for each task did not differ between experiments. For both easy and difficult tasks, the response times obtained in the simulator showed an initial correlation ($r = 0.54$) to the response times obtained on the road. The response times in the two experiments deviated by only 10 to 13 percent relative to the mean task response time. For an easy task, one lasting approximately 1.8 seconds and requiring only a single glance to the display, the simulator underestimated the response times. For a more difficult task, one lasting over 5 seconds and requiring multiple glances to the display, the simulator overestimated the response times.

Since the error between the simulator predictions and the on-the-road response times was proportional to the task difficulty (task mean response time), the error may be caused by one of several factors not explored in these experiments. The most likely cause stems from the fact that in comparing the simulator and the on-the-road studies, no attempt was made to match the roads used. The simulator used a virtual road with more frequent curves and sharper curves than presented in the real world. A more difficult virtual road could cause the simulator to overestimate the response time in a multiple glance task as the driver is forced to allocate more resources to driving by either lengthening the interglance interval or adopting a strategy of using an increased number of shorter glances.

In validating the driving-simulator predictions, simply verifying the mean response times does not guarantee that the simulator predictions will hold. The two methods should agree as to which factors are important and to the relative size and trend of each factor. The simulator accurately predicted the age effect within 3 percent of the task mean, and it predicted the important interactions with age. Likewise, the simulator's prediction of the streets effect matched the same effect observed in the on-the-road experiment.

The only effect that differed between experiments was the point-size effect. The point-size effects were relatively small and near the threshold of detectability when compared with the variability in the experiment. The physical appearance of the text in different point sizes was also near the threshold of detectability for some subjects. Although subjects were tested for far visual acuity, the actual maps were presented at a distance of approximately 40 inches, which is somewhere between far and near acuity. Additionally, only the overall character height was controlled for between experiments. Limitations of the display resolutions changed the character-stroke-width heights between experiments, and the differing vehicle interiors altered the mounting locations slightly. These factors accounted for some of the differences found between the simulator and on-the-road experiments and suggest that when dealing with small effects or near threshold stimuli, the accuracy of the physical locations and hardware display capabilities of the simulated system are important considerations to achieve an accurate prediction.

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APPENDIX A - Participant Consent Forms

Subject #: __________

MAP LEGIBILITY EXPERIMENT
PARTICIPANT CONSENT FORM

The purpose of this experiment is to examine the legibility of electronic maps that might appear in cars of the future.

You will be driving a Ford Taurus station wagon with an automatic transmission on M-14 between US 23 and I-275. While driving, you will read a map shown on a small electronic display on the instrument panel. These map systems are being designed for all types of drivers, regardless of their map reading ability. Data such as speed and lane position will be collected as you drive, and you will be videotaped by several small cameras. We will also record what you say on an audio channel.

This experiment will be conducted in two different sessions (day and night), each lasting about two hours. You will be paid $20 for the first part, $20 for the second part, and a $15 bonus for completing both parts (a total of $55). If you will be unable to attend both sessions, please tell the experimenter before the experiment begins.

****

Your priority is always to drive **safely.** The reading of the electronic maps is secondary. You must **obey all traffic and speed laws**. If you are not driving safely, you will be given one warning, after which the experiment can be stopped. Please tell the experimenter at any time if you feel you are unable to complete the experiment.

****

I HAVE READ AND UNDERSTAND THIS DOCUMENT.

______________________	______________________
Print your name	Date
______________________	______________________
Sign your name	Witness (experimenter)

Subject #: ___________

MAP LEGIBILITY EXPERIMENT
PARTICIPANT CONSENT FORM

The purpose of this experiment is to examine the legibility of electronic maps that might appear in cars of the future.

You will be driving a Ford Taurus station wagon with an automatic transmission on I-94 between M-52 and Baker Road. While driving, you will read a map shown on a small electronic display on the instrument panel. These map systems are being designed for all types of drivers, regardless of their map reading ability. Data such as speed and lane position will be collected as you drive, and you will be videotaped by several small cameras. We will also record what you say on an audio channel.

This experiment will be conducted in two different sessions (day and night), each lasting about two hours. You will be paid $25 for the first part, $25 for the second part, and a $15 bonus for completing both parts (a total of $65). If you will be unable to attend both sessions, please tell the experimenter before the experiment begins.

****

Your priority is always to drive **safely.** The reading of the electronic maps is secondary. You must **obey all traffic and speed laws**. If you are not driving safely, you will be given one warning, after which the experiment can be stopped. Please tell the experimenter at any time if you feel you are unable to complete the experiment.

****

I HAVE READ AND UNDERSTAND THIS DOCUMENT.

______________________ Print your name	______________________ Date
______________________ Sign your name	______________________ Witness (experimenter)

APPENDIX B - Subject Biographical Form

Map Legibility Study - Biographical Form

University of Michigan Transportation Research Institute
Human Factors Division
Biographical Form

Subject: ______

Date: ______

Name: ______________________

Male **Female** (circle one) **Age:** ________

Occupation: ______________________

Retired or student: Note your former occupation or major ______________

What kind of car do you drive the most?

Year: ________ Make: ____________ Model: ____________

Approximate annual mileage: ____________

Have you ever driven a vehicle with an in-vehicle navigation system?

No Yes, in an experiment Yes, elsewhere

In the last 6 months, how many times have you used a map?

0 1-2 3-4 5-6 7-8 9 or more

How often do you use a computer?

Daily A few times a week A few times a month Once in awhile Never

TITMUS VISION: (Landolt Rings)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	Vision correctors? Y / N
T	R	R	L	T	B	L	R	L	B	R	B	T	R	
20/200	20/100	20/70	20/50	20/40	20/35	20/30	20/25	20/22	20/20	20/18	20/17	20/15	20/13	______ which?

APPENDIX C - Instructions to Subjects

Hi, My name is (experimenter's name). **Thank you for coming today. Let's go to the conference room and get started.**

Overview

This study will consist of two on-the-road sessions that will take about two hours each. You will be paid a total of ($55 or $65 depending on which road the subject will be driving) **for your time. After the first session, you will receive** ($20 or $25). **For the second session you will receive** ($20 or $25) **and an addition $15 bonus for completing both sessions. You will be driving a Ford Taurus station wagon with an automatic transmission on** (I-94 or M-14) **(an expressway). Follow all traffic laws and speed limits while driving. If you do not drive safely, the experiment will be stopped.**

This study concerns the design of electronic maps. While driving, you will read a map shown on a small electronic display on the instrument panel and answer a question about the map using a keypad. An example of a question would be as follows: Is the name of the street your vehicle is currently on a male or female name? (Press M for male or F for female) These map systems are being designed for all types of drivers, regardless of their map reading ability. During the experiment data such as speed and lane position will be collected, and you will be videotaped by several small cameras. We will also record what you say on an audio channel. Before we start, there are some forms I need you to fill out. Afterwards, I will give you more detailed instructions.

Consent and Bio Forms

First, please read and sign this consent form, and then fill out the biographical form. If you have any questions feel free to ask them at any time.

Provide consent and biographical forms. Check that it is legible and complete.

It is necessary that we check your eyesight before we begin the experiment.

Vision Test

Next, I'll be checking your vision. Do you use any corrective eye wear while you drive? If subject answers yes - **Could you please put them on?** Subject puts face up to vision tester. **Can you see in the first diamond that the top circle is complete but the other 3 are broken? In each diamond, tell me the location of the solid circle - top, left, bottom, or right.** Continue until 2 in a row are wrong. Take the last one that was correct as the visual acuity.
I also need to see your driver's license. Check license.

At the test vehicle

Let me reiterate a few important points from the consent form. First of all, driving safely is your main priority. If you feel unsafe or unable to make any turn, please don't. Second, if you are uncomfortable or wish to stop at any time, please let me know right away. You are expected to obey all speed limits and driving laws. The speed limit on M-14 is 65 mph through the section we will be driving, but we ask that you maintain 55 mph during the experiment.

Please fasten your seat belt, adjust the seat, mirrors, steering wheel height, as you feel necessary.

- adjust the car seat, steering wheel height, and side- and rear-view mirrors.
- Fasten seat belt.
- Point out climate controls, and radio volume knob.
- Adjust eye fixation camera once subject is comfortable.
- Remind about following speed limit.
- After Vehicle is started, turn on computer and adjust rear monitor.
- Start up ToyotaMap by double clicking on the icon.

Overview while Still At UMTRI
(sit up front at this point and make sure camera's focused)

This is a study to determine how different features affect the ease of reading a map. Some of these factors of interest are the street name font size and the number of streets on the map.

For the first stretch you will just practice driving with your left hand on the wheel and your right hand on the keypad while familiarizing yourself with the route. Subsequent trips will add either practice tasks or experimental tasks using the keypad to answer questions about the displayed map. Each task will have a specific question associated with the entire task. Each task consists of 24 trials.

As an example of what to expect, for your first practice session, you'll be shown one name on the display screen to your right and then answer the question of whether that name is male or female.

Point out Display and Keypad.
Adjust Keypad and arm rests so that the driver is comfortable.
Show Task one Fingering and how to steady hand.

For Example:
Play Demo of Practice 1 (Command Key 1)
Adjust Radio Volume

As you noticed a "ding" will sound each time before the name appears to notify you of a change in the map. The name will either be a male or female name. Your task is to determine whether the name is male or female and to respond by pressing the appropriate button on the keypad to your right. Quickly press and release the left key (marked "M") if the name you see is male, such as John. If the name is female, such as Jane, press the key marked "F."

Subject responds correctly.

A correct answer is responded to with a "simple beep". An incorrect answer will be responded to with a "buzzer" tone. If you answer incorrectly, do not try to respond again; just move on to the next slide.

Replay Demo of Practice 1 (Command Key 1)
Subject responds incorrectly.

I will briefly demonstrate each of the remaining tasks for you now, but you need not memorize the specifics. I will go over each task again just prior to its start. The first task, Task 1, will be to decide the gender of the street on which your vehicle icon is traveling.

Play Demo of Task 1 (Command Key 2)

Again, a "ding" will sound and a map will appear. Locate your vehicle icon. Locate the street name. Decide whether that name is male or female. Respond with M or F on the keypad.

Note: At night, show the subject where the display brightness/contrast dial is and have the subject adjust it at this point to his or her liking.

The next task, Task 2, will have the same responses, "M" and "F" as task one, but will also add the next key "Not there." You will be given the "number" of a cross street to locate on the map. The map will appear after the number is read (There is no "ding" this time).

Play Demo of Task 2 (Command Key 3)

Locate your vehicle icon and the street you are on. Count up the specified number of cross streets. Note that a cross street is defined as intersecting the street you are on or more simply, any street that you can turn onto. When you find the specified cross street locate its name and respond with answers for this task are M (male), F (female), or 0 (not there).

Play Demo of Task 2 (Command Keys 4)

In the next two sets you will need to change your fingering position.

Show new fingering and how to steady hand.

You will be responding Ahead (middle finger), **Behind** (middle finger), **Left** (index finger), **Right** (ring finger), **or Not There** (middle finger).

Play Demo of Practice 2 (Command Key 5)

In this practice set a "ding" will sound and a map will appear. Find the bolded street on the map. Determine its position relative to your vehicle icon and respond. Note that Ahead and Behind only apply to cross streets, streets that intersects the street your on which your vehicle icon is traveling.

Play Demo of Practice 2 (Command Keys 6 and 7)

The final task uses the same response keys only this time you will hear the name of a street instead of a "ding."

Play Demo of Task 3 (Command Key 8)

The map will appear after the name is read. Search the map and locate that street name. Decide and respond with that street's relative location to your vehicle icon with either "Ahead, Behind, Right, Left, or Not There."

Play Demo of Task 3 (Command Keys 9 and 0)

After Each task I will ask you to rate the difficulty of the task and how you felt during the task on a scale from 1 to 5 with one being...

1. **No Interference with Driving, Very Safe.**
2. **Some Interference, but Safe.**
3. **Some Interference, Sometimes Unsafe.**
4. **Much Interference, Unsafe.**
5. **Extreme Interference, Very Unsafe.**

Remember, I will go over each task in detail before just prior to starting the task, but for now do you have any questions in general about the experiment? If not, we can drive out to M-14 and begin.

Give subject directions to M-14.
Fill in subject data sheet for the file header.

<u>On Road Section 1</u>

•Turn on VCR after passing (Exit 10 for M-14 or Baker Road for I-94).

OK, at this point I'm going to begin recording. I'd like you place your right hand on the keypad and drive with your left hand only (unless of course it's an emergency). Just relax and just drive normally. We will be

getting off the expressway at Beck Road which is about 10 miles ahead. Maintain 55 mph for this stretch of road.

•Exit the expressway at (Beck Road or US 52)
•Give good directions on getting back on the expressway in the correct direction.

On the Scale from 1 to 5, how would you rate this task?

•Clarrify rating scale if needed. Record response in ToyotaMap comment section.

<u>On Road Section 2</u>

On the next stretch of road, I'm going to start the first practice task. As you will remember from the demonstration, in this task you will hear a "ding" and a name will appear in the center of the display to your right. Read the name and decide its gender. Your response will be either M for male or F for female.

Try not to look down at the keypad to respond, and remember, if you answer incorrectly do not worry or try to answer again. Just note it and move on. Also try not to look at the screen until you hear the "ding." Use the time between maps to concentrate on driving and on checking your mirrors.

REMEMBER, your primary task is to maintain control of the vehicle and drive safely at all times. Reading the display and responding are SECONDARY tasks.

Once you have merged with traffic and are maintaining a constant speed between 55 and 65 mph, position your hand comfortably on the keypad and I will begin the task.

Any Questions?

•Begin Practice Task 1

Note: Use the Pause/Resume Feature (Command P/R) to pause the task during a black screen whenever traffic is merging from an on-ramp or whenever cars are pulled over on the right shoulder or any other distractions (Cops, Tow Trucks, Sudden Brake Lights Ahead, etc.). Make a note on scratch paper of the trial you paused and the reason for the pause. Then enter this information into the computer at the end of the task if possible.

•End Practice Task 1

On the Scale from 1 to 5, how would you rate this task?

On Road Section 3

The next task will be very similar to the last practice. You will hear a "ding" and a map will appear on the screen. Locate your vehicle icon (a black arrow). Find the name of the street it is on. Decided whether that name is male or female and respond accordingly.

Any Questions?

When you have merged with traffic and reached a steady speed between 55 and 65 mph we will begin the task.

•Begin Task 1
•End Task 1

On the Scale from 1 to 5, how would you rate this task?

On Road Section 4

In the next task, you will be given the "number" of a cross street and then a map will appear. Locate your vehicle icon. Find the designated cross street. Decide whether that street name is Male, Female or whether that street is not on the map. You will have the same responses as the last task only adding the "Not There" response. If you need the number of the cross street repeated, just ask.

This task is a little bit more challenging than the last two, make sure you focus on driving safely at all times.

Any Questions?

•Begin Task 2
•End Task 2

Note: To Replay the Voice Sample press (Command V).
On the Scale from 1 to 5, how would you rate this task?

On Road Section 5

In this next task I would like you to change your finger position from the "Male/Female" keys to the "Arrow Keys." You will probably want to pick up the keypad and move it down closer to you for more comfort. Go ahead and adjust that at your convenience.

In this practice task, you will hear a "ding" and a map will appear. Search the map for a bolded street. Determine that street's position relative to your vehicle icon. Respond with "Ahead, Behind, Left, Right, or Not There." Try to learn the keypad and responses so that you do not need to look down at it in order to respond.

Any Questions?

•Begin Practice Task 2
•End Practice Task 2

On the Scale from 1 to 5, how would you rate this task?

<u>On Road Section 6</u>

The next task will be very similar to the last task only this time you will be given the name of a street. After the name is spoken, a map will appear on the screen. Search the map for the named street and decide that street's location relative to your vehicle icon. Respond with either Ahead, Behind, Left, Right or "Not There." You should not need to look down at the keypad in order to respond.

Be aware that this task may be challenging and you may have a tendency to ignore your driving responsibilities as you become engulfed in the task. Remember that your PRIMARY responsibility is to drive safely and that should take precedence over responding to the maps.

Any Questions?

•Begin Task 3
•End Task 3

Note: To Replay the Voice Sample press (Command V)

On the Scale from 1 to 5, how would you rate this task?

At this point we are finished with the experiment. You will probably want to accelerate up to the posted speed limit and move over to the left lane so that you can take the (US 23 South or M-14 East Exit) **and head back to UMTRI.**

Save Data File
Copy Data File to a Floppy Disk
Shut down the computer and turn off the power inverter.

<u>At UMTRI</u>

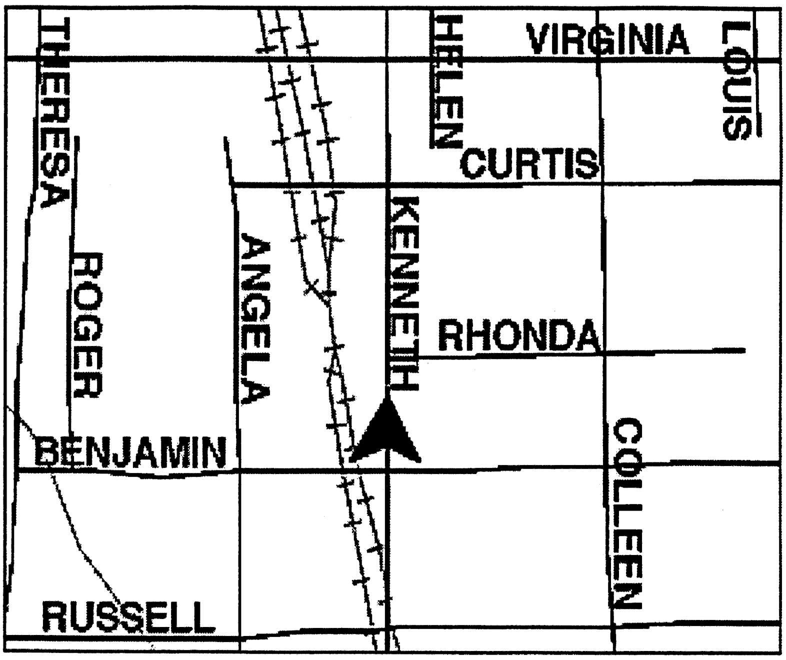
If you could come up to the office with me so I can fill out the payment form and get you your money for today.

Fill out forms.

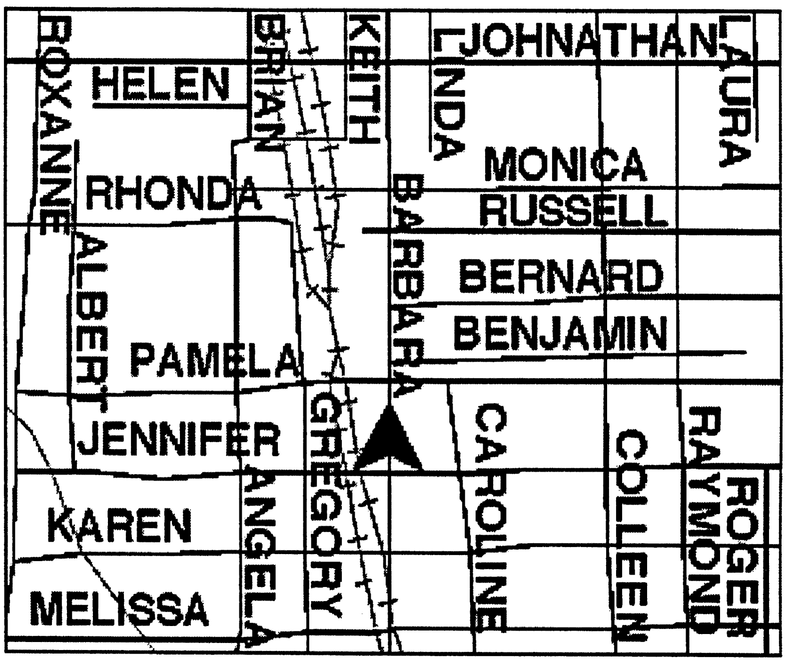
Thank you for participating today, I will see you sometime next week for the second session.

APPENDIX D - Map Examples and Discussion

Map Template 1 Examples

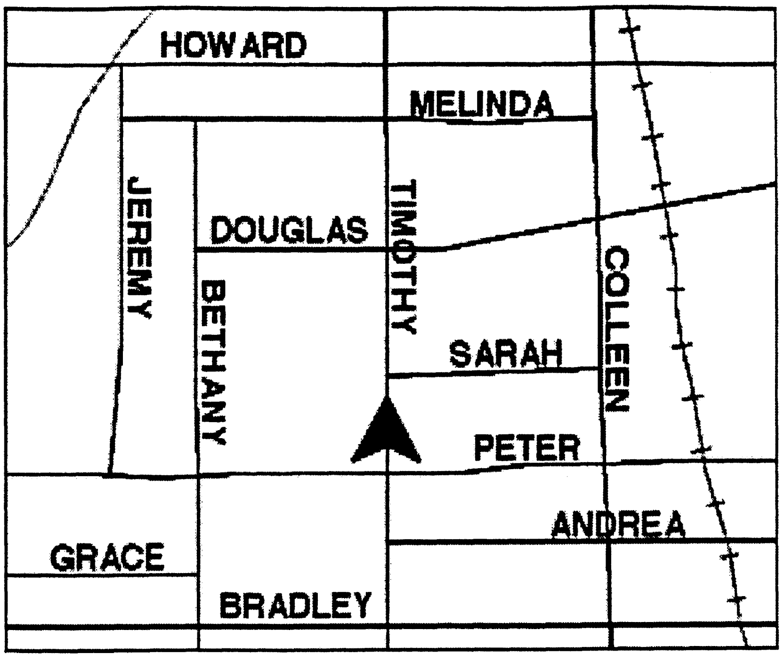


12 Streets, 12 Point

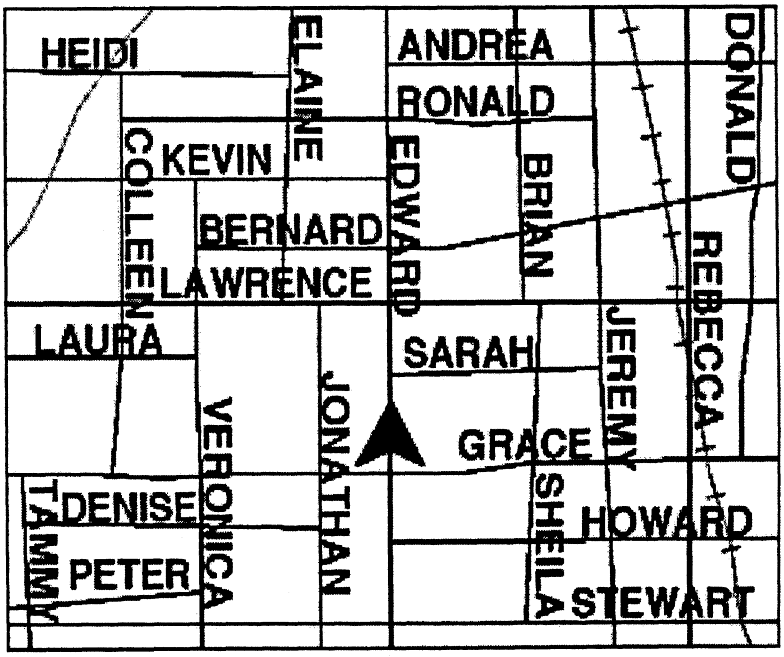


24 Streets, 14 Point

Map Template 2 Examples

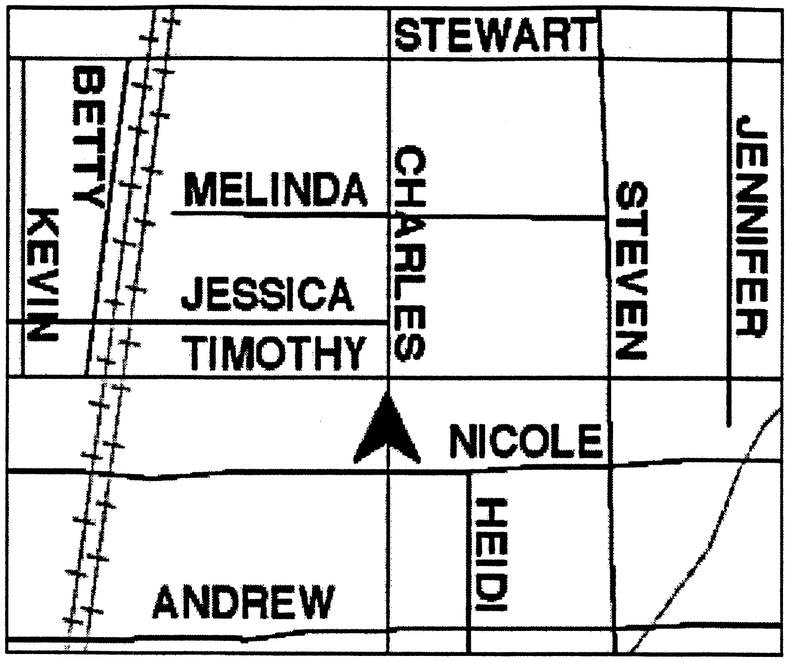


12 Streets, 10 Point

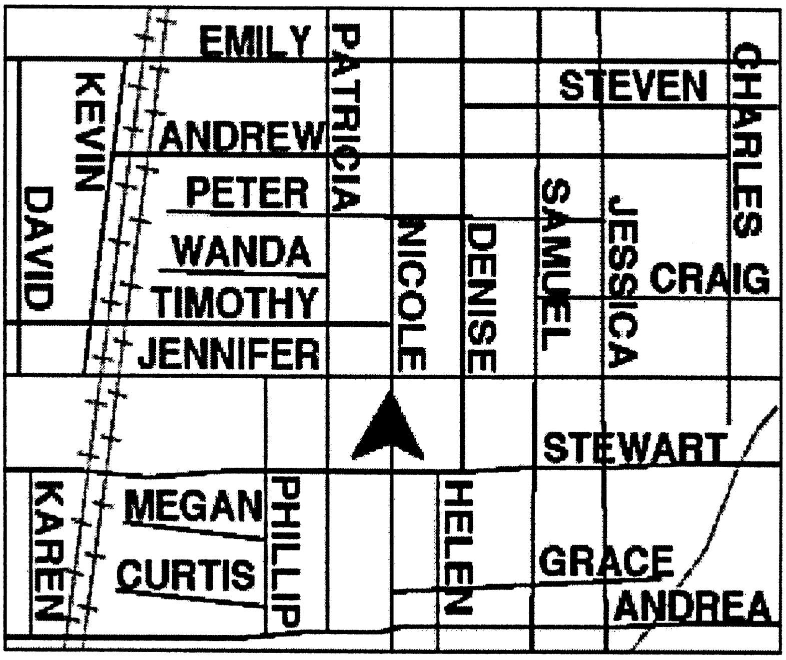


24 Streets, 12 Point

Map Template 3 Examples

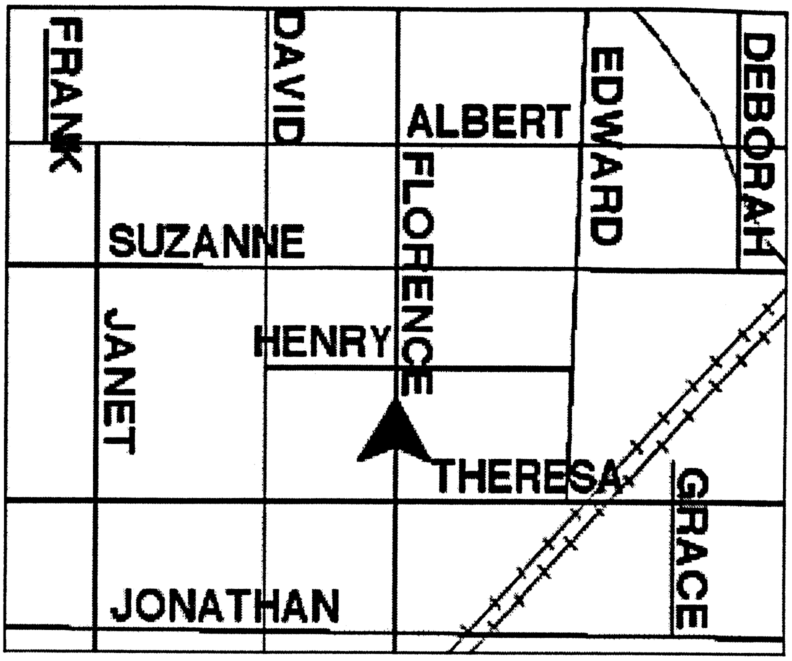


12 Streets, 14 Point

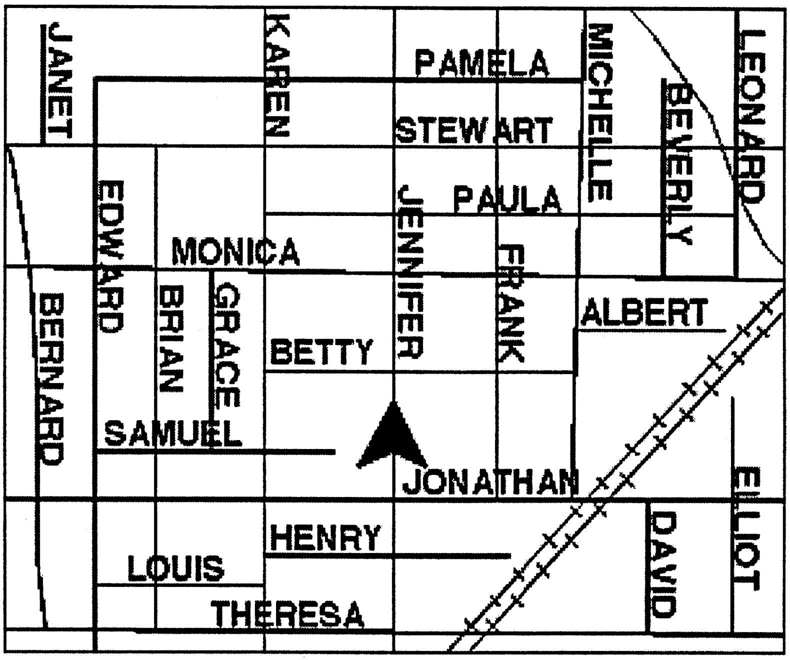


24 Streets, 12 Point

Map Template 4 Examples



12 Streets, 14 Point



24 Streets, 10 Point

Map Template Discussion

Four map templates were used to avoid map configuration artifacts and memorization of the maps during the experiment. Although Tasks 2 and 3 assumed that no differences existed between map templates, Task 1 included the map template as a factor to verify this hypothesis. Differences between map templates in Task 1, though as large as 125 ms, were not significant. Any perceived differences between map templates were likely due to the effects of long trials. Removing 1.5 percent of the trials (11 trials), all with response times above 4 seconds (the task mean + 3*SD) decreased the maximum difference between any two map templates by 48 percent (60 ms) as shown in Figure 53.

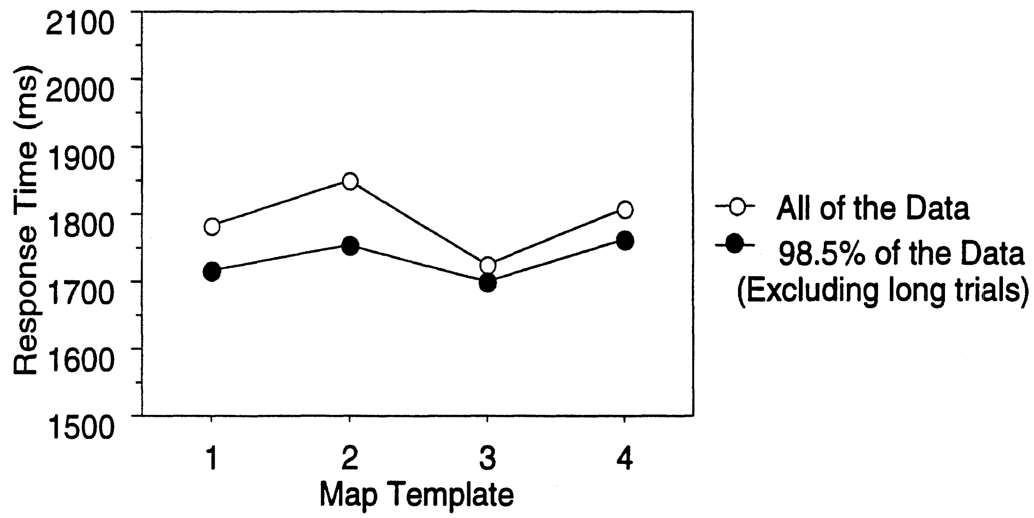


Figure 53. Task 1: Effects of long trials on the map template factor.

APPENDIX E - Experimental Conditions by Task

Practice 1 Experimental Conditions

Slide #	Response	Point	Name	Start
1	Male	10	Bruce	Start 1
2	Female	12	Gloria	
3	Male	14	Elliot	
4	Male	10	Benjamin	
5	Male	12	Samuel	
6	Female	10	Melinda	Start 2
7	Female	14	Charlotte	
8	Female	10	Marie	
9	Male	12	Albert	
10	Female	10	Heidi	
11	Female	14	Victoria	Start 3
12	Male	10	Dennis	
13	Female	12	Judith	
14	Male	14	Walter	
15	Female	14	Donna	
16	Female	12	Angela	Start 4
17	Male	10	Brian	
18	Male	14	Curtis	
19	Female	12	Laura	
20	Male	14	Phillip	
21	Female	10	Emily	Start 5
22	Male	12	Clifford	
23	Male	14	Russell	
24	Female	12	Rhonda	

Task 1 Experimental Conditions

Slide #	Streets	Point	Map	Response	Name	Start
1	12	14	4	Female	Florence	Start 1
2	12	10	1	Female	Jessica	
3	24	12	2	Male	Edward	
4	12	14	3	Male	Charles	
5	12	10	4	Male	Joshua	
6	24	14	2	Female	Michelle	Start 2
7	24	10	3	Male	Douglas	
8	24	10	1	Male	Gregory	
9	12	10	3	Female	Andrea	
10	12	12	2	Female	Elaine	
11	24	14	4	Male	Michael	Start 3
12	24	12	1	Male	Steven	
13	12	14	2	Female	Patricia	
14	24	12	3	Female	Nicole	
15	24	10	4	Female	Jennifer	
16	12	12	1	Male	Kenneth	Start 4
17	12	12	3	Female	Colleen	
18	24	10	2	Male	Bradley	
19	12	14	1	Female	Theresa	
20	12	12	4	Female	Megan	
21	24	14	3	Male	Andrew	Start 5
22	12	10	2	Male	Timothy	
23	24	14	1	Female	Barbara	
24	24	12	4	Male	Matthew	

Task 2 Experimental Conditions

Slide	# Streets	Point	Map	Response	X-Street	Name	Start
1	24	14	2	Male	6	Nathan	Start 1
2	12	10	1	Not There	4	Not There	
3	12	14	3	Male	4	Joseph	
4	24	12	3	Not There	6	Not There	
5	12	10	2	Female	1	Denise	
6	12	10	3	Female	4	Bethany	Start 2
7	24	14	1	Male	3	Jonathan	
8	24	14	4	Not There	6	Not There	
9	12	12	2	Female	4	Margaret	
10	24	12	4	Female	1	Paula	
11	12	12	4	Male	3	James	Start 3
12	24	14	3	Female	1	Monica	
13	12	14	1	Female	1	Melissa	
14	24	12	2	Male	3	Joshua	
15	12	12	1	Not There	4	Not There	
16	24	10	3	Male	3	Richard	Start 4
17	12	10	4	Female	3	Pamela	
18	24	10	4	Not There	6	Not There	
19	24	12	1	Male	6	Robert	
20	12	12	3	Female	1	Grace	
21	24	10	1	Female	6	Caroline	Start 5
22	12	14	2	Male	3	Jeremy	
23	24	10	2	Male	1	Marvin	
24	12	14	4	Not There	4	Not There	

Practice 2 Experimental Conditions

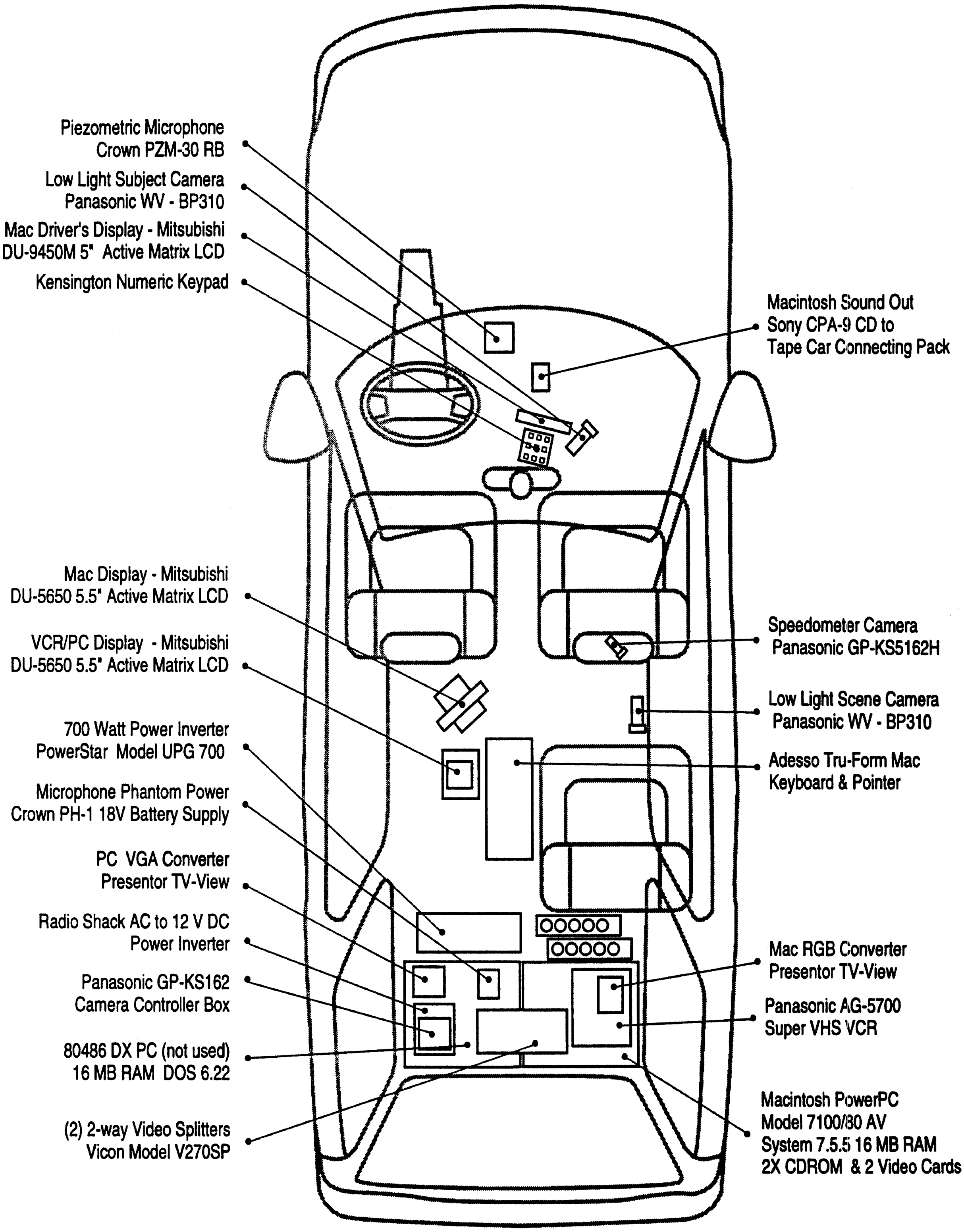
Slide #	Streets	Map	Response	Start
1	12	3	Ahead	Start 1
2	24	1	Left	
3	24	4	Not There	
4	12	2	Behind	
5	24	2	Not There	
6	24	4	Left	Start 2
7	12	3	Ahead	
8	24	3	Not There	
9	12	1	Behind	
10	24	1	Ahead	
11	24	4	Right	Start 3
12	24	2	Behind	
13	12	2	Not There	
14	12	1	Right	
15	12	4	Behind	
16	12	3	Ahead	Start 4
17	12	2	Not There	
18	12	4	Right	
19	24	3	Ahead	
20	12	4	Not There	
21	24	2	Behind	Start 5
22	12	1	Not There	
23	24	3	Ahead	
24	24	1	Behind	

Task 3 Experimental Conditions

Slide	# Streets	Point	Map	Response	Name	Start
1	12	12	3	Right	Jessica	Start 1
2	12	10	4	Behind	Robert	
3	24	14	3	Ahead	Timothy	
4	24	12	1	Not There	Donna	
5	24	12	4	Ahead	Jonathan	
6	24	12	3	Left	Martin	Start 2
7	12	14	3	Not There	Bradley	
8	12	14	4	Right	Angela	
9	24	10	2	Behind	Tammy	
10	12	12	2	Not There	Michelle	
11	12	10	2	Ahead	Douglas	Start 3
12	24	14	2	Behind	Denise	
13	24	14	1	Not There	Craig	
14	12	10	1	Left	Monica	
15	24	12	2	Behind	Stewart	
16	12	12	4	Ahead	James	Start 4
17	24	10	1	Right	Sarah	
18	12	10	3	Not There	Karen	
19	12	12	1	Behind	Curtis	
20	24	10	4	Ahead	Thomas	
21	12	14	2	Behind	Melinda	Start 5
22	24	14	4	Left	Nicole	
23	24	10	3	Not There	Colleen	
24	12	14	1	Ahead	Jeffery	

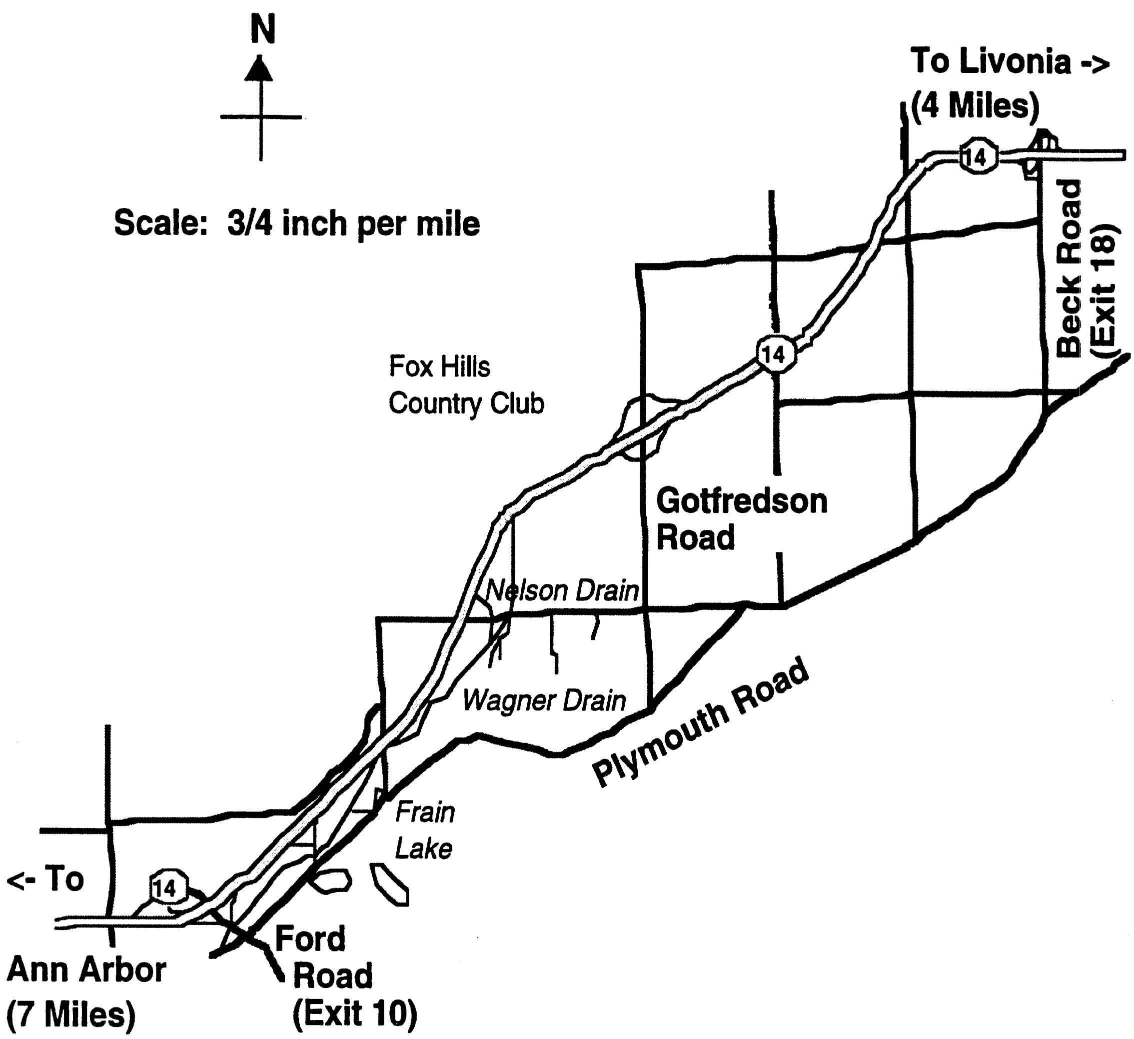
APPENDIX F - Test Vehicle Illustrations

1992 Ford Taurus Station Wagon



APPENDIX G - Test Routes

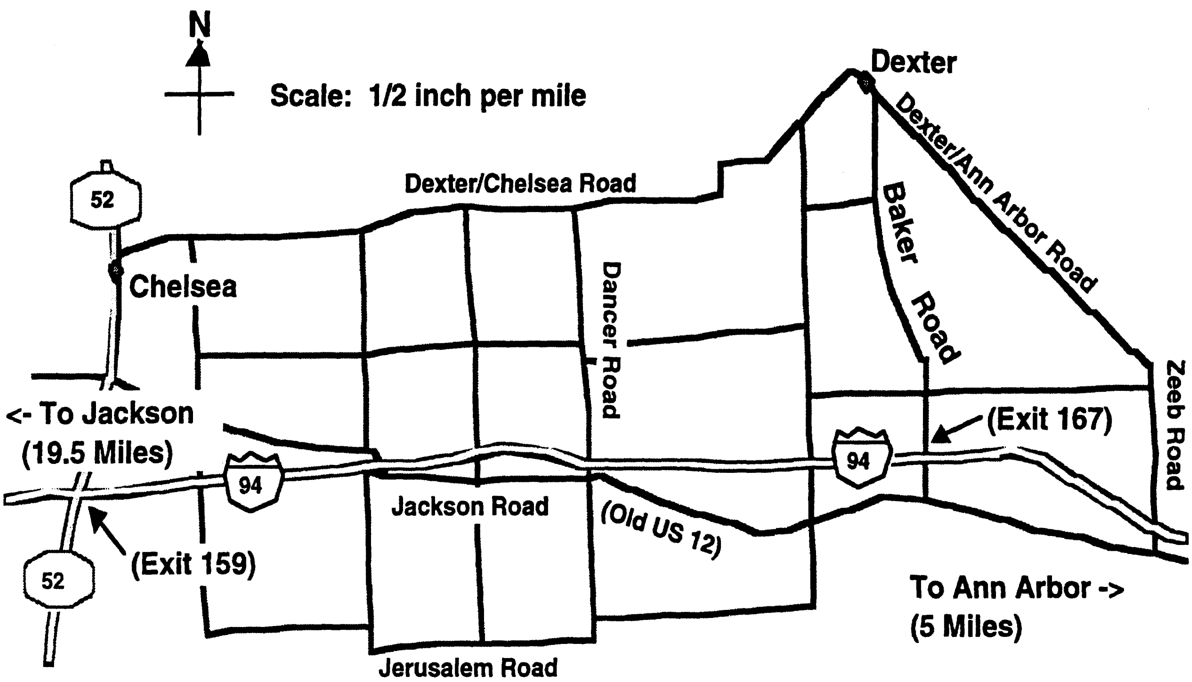
M-14 Test Route



M-14 Trip and Task Description

Trip Number	Enter at	Exit at	Travel Direction	Task Description
1	Ford road	Beck road	east	Practice driving with one hand.
2	Beck road	Ford road	west	Practice set 1
3	Ford road	Beck road	east	Task 1
4	Beck road	Ford road	west	Task 2
5	Ford road	Beck road	east	Practice set 2
6	Beck road	Ford road	west	Task 3

I-94 Test Route



I-94 Trip and Task Description

Trip Number	Enter at	Exit at	Travel Direction	Task Description
1	Baker road	US 52	west	Practice driving with one hand
2	US 52	Baker road	east	Practice set 1
3	Baker road	US 52	west	Task 1
4	US 52	Baker road	east	Task 2
5	Baker road	US 52	west	Practice set 2
6	US 52	Baker road	east	Task 3

Test Route Discussion

Although construction necessitated a change in the test road, the effect of road on response time was not statistically significant for any of the tasks. The mean response time differences between roads was 95 ms, Task 1; 60 ms, Task 2; and 1040 ms, Task 3.

Any higher order interactions with the road in Task 1 were likely due to individual differences. The mean response time for mature men (2020±90 ms) was equal to the mean response time for mature women (2020±220 ms); however, the mature subjects' mean response times varied from 1790 ms to 2520 ms with the individual subject means being distributed at either the upper or lower end of the spectrum. Figure 54 shows that in Task 1 the two faster women both drove on one road (I-94) rather than being distributed across roads as in the mature male category.

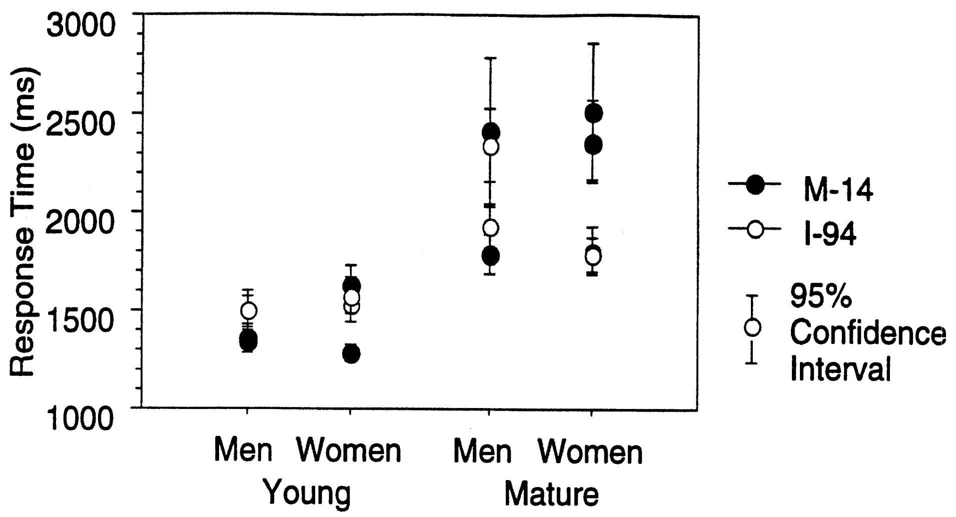


Figure 54. Task 1: Subjects' mean response times.

As in Task 1, any road effects seen in Task 3 probably reflect individual subject differences. Figure 55 shows that the overall difference between roads (1040 ms) is largely due to the individual differences between the mature women who drove each road. Excluding the mature women from the analysis, the difference between M-14 and I-94 drops by 61 percent to only 400 ms.

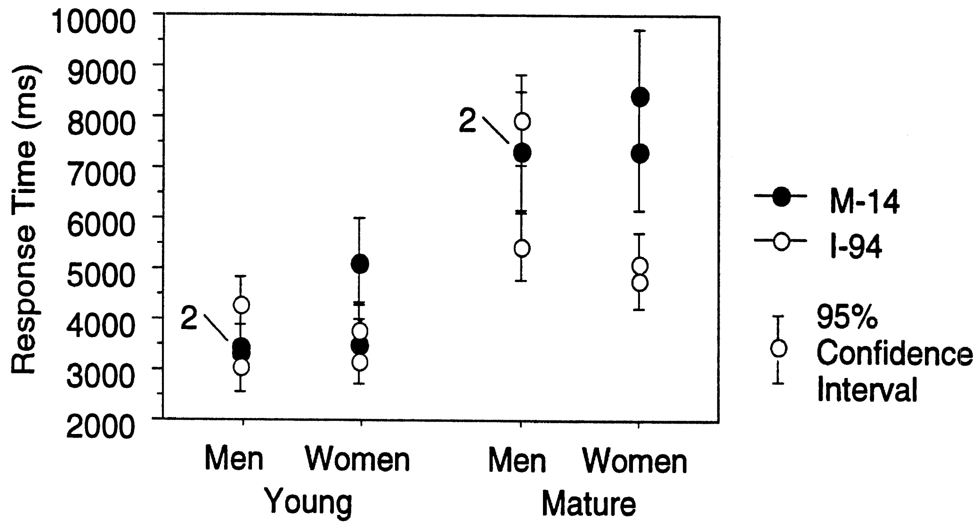


Figure 55. Task 3: Subjects' mean response times.

APPENDIX H - Listing of Invalid Trials and Outliers by Task

Task 1: What street are you on?

Subject Number	Subject mean ± SD	Outlier Response Time (ms)	New Response Time (ms)	Comments
10	2570±1770	10,617	2994	This was the first trial by the subject. After 5 glances to the screen the subject decided to put on his reading glasses for the remainder of the experiment.
13	2630±1642	10,583	5016	This trial was a 10 pt, 24-street map. The subject reported difficulty reading the 10 pt names in general and also had trouble identifying the name "Gregory."

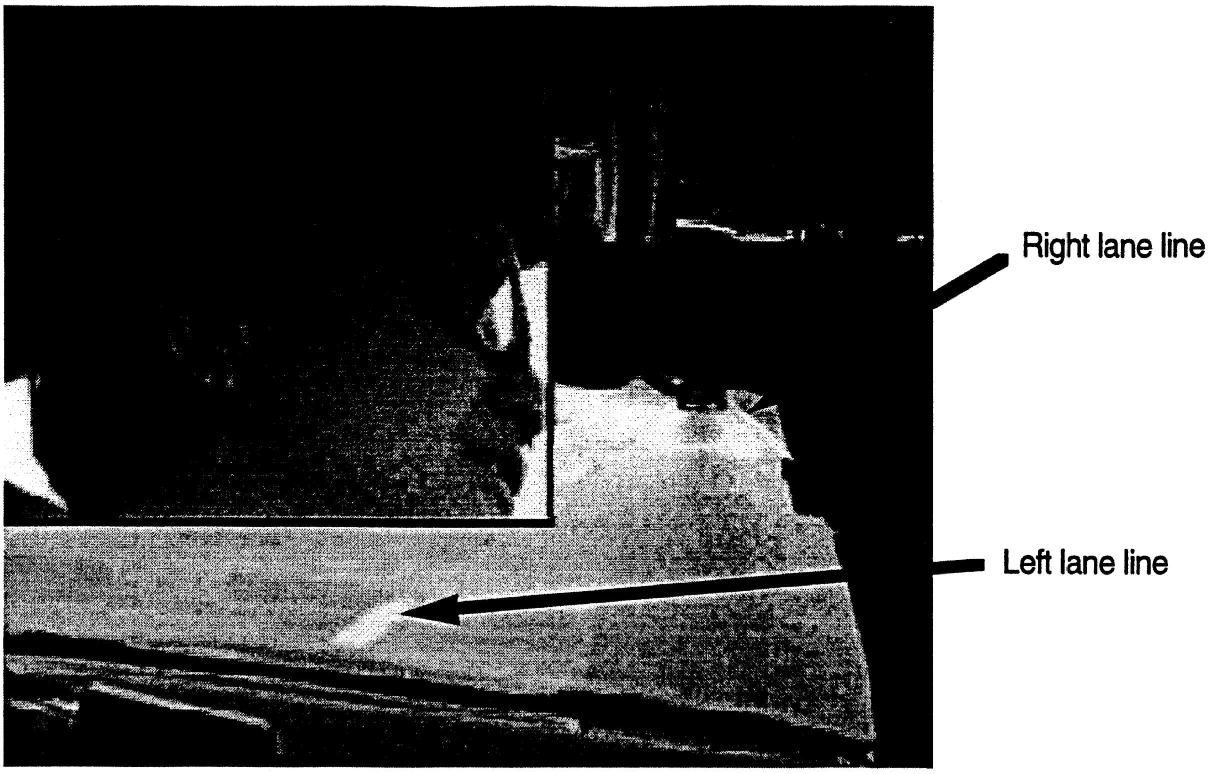
Task 2: What is the nth cross street?

Subject Number	Subject mean ± SD	Outlier Response Time (ms)	New Response Time (ms)	Comments
4	3110±1870	6000	6000	The subject was distracted during the trial when a truck in front of the test vehicle lost control.
9	4000±2750	15967	10500	The subject had his hand in the wrong position and kept a key that he thought was correct but did not actually respond to the task. The new response time was estimated from video analysis.
9	4000±2750	10717	10717	The subject was not paying attention at the start of the trial and then asked a question during the trial, but the impact was minimal.
10	4120±1960	3200	3200	The subject did not hear the target cross street when it was first read.
13	4410±3330	22200	2880	The subject became confused and the task was re-explained during this trial.
15	2860±1350	167	4372	A bump in the road caused the subject to accidentally hit "a" at the start of the trial.

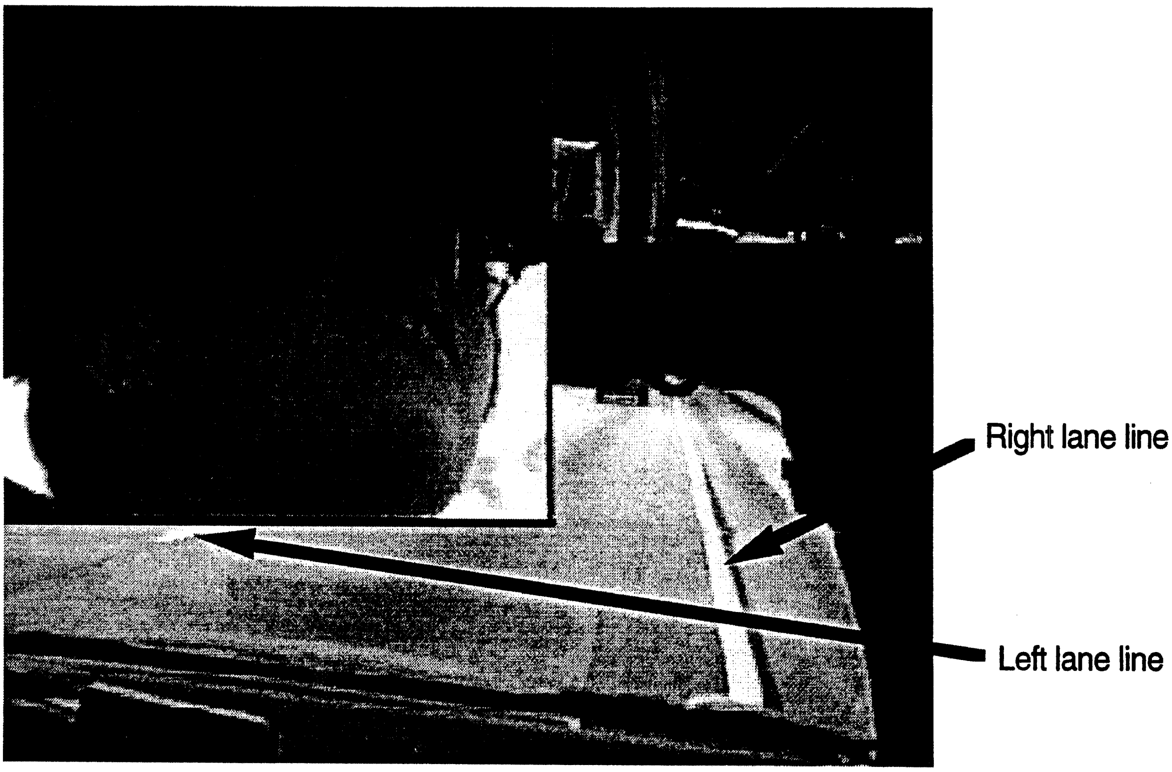
Task 3: Where is the named street?

Subject Number	Subject mean ± SD	Outlier Response Time (ms)	New Response Time (ms)	Comments
10	7320±3290	11,717	11,717	The target street was "Curtis" but the subject had difficulty understanding the sound byte mistaking it for "Julius."
12	7950±3080	7417	7417	This trial was marked invalid because the subject did not hear the target street name the first time.
15	4800±2060	3883	3883	The subject accidentally hit a key before she was ready to respond.
16	5090±2230	4933	4933	The subject did not hear the target street correctly. She heard "Robin" when the name was actually "Robert."

APPENDIX I - Lane Crossing Benchmark Images



Left lane crossing



Right lane crossing

APPENDIX J - Table of Task 1 Error Trials

Subject		Number	Point	Name	Frequency
Age	Gender	of Streets	Size		Missed
Young	Women	12	10	Joshua	1
Mature	Women	12	10	Joshua	1
Mature	Men	12	10	Andrea	1
Mature	Women	12	10	Timothy	1
Young	Women	12	12	Elaine	1
Young	Women	12	12	Colleen	1
Young	Women	12	12	Megan	1
Mature	Women	12	14	Florence	1
Young	Men	24	10	Bradley	1
Mature	Women	24	10	Jennifer	1
Young	Men	24	14	Andrew	1
Mature	Women	24	14	Michelle	2
Mature	Men	24	14	Michael	1

APPENDIX K - Task 1 Response Time ANOVA Table

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Between Subject Factors					
Age	1	8.157 E7	8.157 E7	25.386	<.001
Gender	1	243675.000	243675.000	.076	.79
Age * Gender	1	316712.521	316712.521	.099	.76
Time Sequence	1	4082750.021	4082750.021	1.271	.28
Road	1	1742884.630	1742884.630	.542	.48
Subject(Group)	10	32131432.703	32131432.703	-	-
Within Subject Factors					
Time of Day	1	4998752.083	4998752.083	2.749	.13
Time * Time Sequence	1	1605642.521	1605642.521	.883	.37
Time * Age	1	674739.188	674739.188	.371	.56
Map Template	3	1524035.292	508011.764	2.255	.10
Number of Streets	1	1256474.083	1256474.083	4.737	.055
Streets * Age	1	301467.000	301467.000	1.137	.31
Streets * Time	1	106974.083	106974.083	.484	.50
Point Size	2	4039108.003	2019554.001	4.665	.028
Point Size * Age	2	2121796.284	1060898.142	2.451	.11
Point Size * Time	2	52957.284	26478.642	.116	.89
Point Size * Streets	2	2084723.909	1042361.954	3.685	.043

Note: The actual ANOVA model used a full factorial of the within-subject main effects (time of day, map template, number of streets and point size) fully crossed with each of the between-subject factors listed in the table above. Due to the length of this model, this ANOVA table has been abridged to include only the main effects and interactions which were expected to yield significant results. The remaining higher order interactions were calculated but not reported.

APPENDIX L - Task 2 Response Time ANOVA Table

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Between Subject Factors					
Age	1	2.522 E8	2.522 E8	18.853	.0015
Gender	1	524746.908	524746.908	.039	.85
Age * Gender	1	90588.908	90588.908	.007	.94
Time Sequence	1	21003617.251	21003617.251	1.570	.24
Road	1	638312.345	638312.345	.048	.83
Subject(Group)	10	1.338 E8	1.338 E7	-	-
Within Subject Factors					
Time of Day	1	6991942.501	6991942.501	.895	.37
Time * Time Sequence	1	33263786.314	33263786.314	4.258	.066
Time * Age	1	552391.158	552391.158	.071	.80
Point Size	2	319834.956	159917.478	.136	.87
Point Size * Age	2	56206.893	28103.447	.024	.98
Point Size * Time of Day	2	375340.346	187670.173	.109	.90
Condition	7	8.334 E8	1.191 E8	44.571	<.001
Condition * Age	7	26784585.624	3826369.375	1.432	.21
Condtion * Time of Day	7	14943167.780	2134309.683	1.961	.073
Condtion * Point Size	14	90036451.857	6431175.133	4.823	<.001
Linear Contrasts within Condtion					
Number of Streets	1	24784305.042	24784305.042	9.278	.0033
Cross Street Named	1	1.430 E8	1.430 E8	53.539	<.001
Streets * Cross Street	1	24238590.042	24238590.042	9.074	.0036
Response of "not there"	1	1149859.815	1149859.815	.430	.51

Note: The actual ANOVA model used a full factorial of the within-subject main effects (time of day, point size, and condition) fully crossed with each of the between-subject factors listed in the table above. Due to the length of this model, this ANOVA table has been abridged to include only the main effects and interactions which were expected to yield significant results. The remaining higher order interactions were calculated but not reported.

APPENDIX M - Task 3 Error ANOVA Table

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Between Subject Factors					
Age	1	4.688	4.688	54.396	<.001
Gender	1	0.021	0.021	0.242	.63
Time Sequence	1	0.000	0.000	0.000	1.00
Road	1	0.255	0.255	2.962	.11
Subject(Group)	11	0.948	0.086	-	-
Within Subject Factors					
Time of Day	1	0.188	0.188	1.932	.19
Time * Time Sequence	1	0.047	0.047	0.483	.50
Time * Age	1	0.047	0.047	0.483	.50
Number of Streets	1	0.521	0.521	16.923	.0017
Streets * Age	1	0.047	0.047	1.523	.24
Streets * Time of Day	1	0.005	0.005	0.071	.79
Point Size	2	0.492	0.246	4.340	.026
Point Size * Age	2	0.477	0.238	4.203	.029
Point Size * Time of Day	2	0.445	0.223	2.795	.083
Point Size * Streets	2	0.456	0.228	1.453	.26
Response Location	3	5.818	1.939	10.893	<.001
Location * Age	3	3.719	1.240	6.963	<.001
Location * Time of Day	3	0.344	0.115	1.147	.34
Location * Streets	3	0.740	0.247	2.321	.093
Location * Point Size	6	1.268	0.211	1.847	.10

Note: The actual ANOVA model used a full factorial of the within-subject main effects (time of day, number of streets, point size, and location) fully crossed with each of the between-subject factors listed in the table above. Due to the length of this model, this ANOVA table has been abridged to include only the main effects and interactions which were expected to yield significant results. The remaining higher order interactions were calculated but not reported.

APPENDIX N - Task 3 Response Time ANOVA Table

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Between Subject					
Age	1	1.729 E9	1.729 E9	54.170	.0018
Gender	1	2779820.345	2779820.345	.087	.78
Age * Gender	1	42933739.876	42933739.876	1.345	.31
Time Sequence	1	10160250.293	10160250.293	.318	.60
Road	1	2.086 E8	2.086 E8	6.534	.063
Subject(Group)	4	1.277 E8	1.277 E8	-	-
Within Subject					
Time of Day	1	5614101.001	5614101.001	6.136	.068
Time * Time Sequence	1	1205630.262	1205630.262	.145	.72
Time * Age	1	5614101.001	5614101.001	.675	.46
Number of Streets	1	9.766 E8	9.766 E8	129.465	<.001
Streets * Age	1	74923144.699	74923144.699	9.932	.035
Streets * Time of Day	1	2124471.939	2124471.939	1.008	.37
Point Size	2	13523262.469	13523262.469	2.354	.16
Point Size * Age	2	948384.042	474192.021	.165	.85
Point Size * Time of Day	2	29156299.719	1.458 E7	3.261	.092
Point Size * Streets	2	21100079.823	1.055 E7	2.915	.11
Response Location	3	1.188 E9	3.961 E8	54.950	<.001
Location * Age	3	56556083.900	1.885 E7	2.615	.10
Location * Time of Day	3	37350408.473	1.245 E7	6.030	.0096
Location * Streets	3	1.551 E8	5.170 E7	8.051	.0033
Location * Point Size	6	46661830.208	7776971.701	1.982	.11

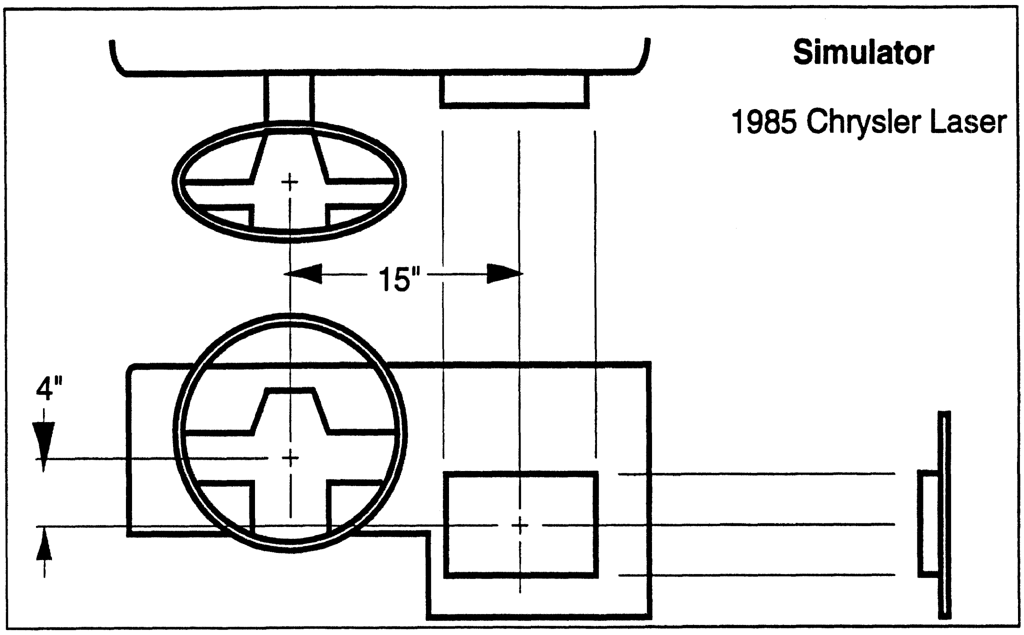
Note: The actual ANOVA model used a full factorial of the within-subject main effects (time of day, number of streets, point size, and location) fully crossed with each of the between-subject factors listed in the table above. Due to the length of this model, this ANOVA table has been abridged to include only the main effects and interactions which were expected to yield significant results. The remaining higher order interactions were calculated but not reported.

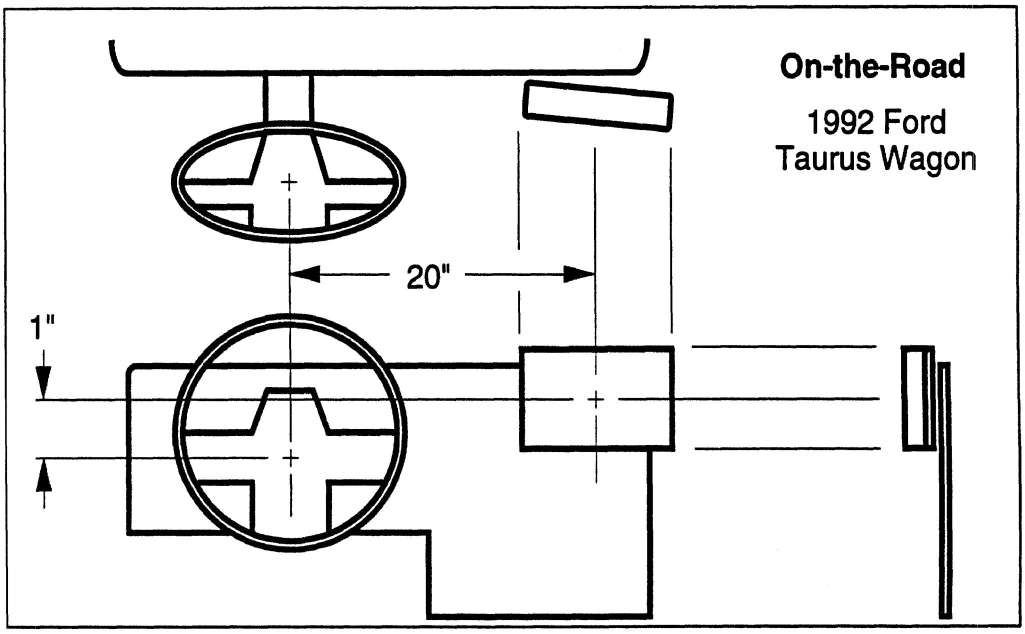
APPENDIX O - Simulator Validation Task 1 ANOVA Table

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Between Subject					
Age	1	24613605.337	24613605.337	65.631	<.001
Gender	1	626350.890	626350.890	1.670	.21
Age * Gender	1	892304.116	892304.116	2.379	.13
Experiment	1	1239520.133	1239520.133	3.305	.08
Experiment * Age	1	40480.133	40480.133	.108	.74
Subject(Group)	30	11250945.524	375031.517	-	-
Within Subject					
Number of Streets	1	189302.872	189302.872	2.006	.17
Streets * Age	1	46282.315	46282.315	.491	.49
Streets * Experiment	1	24239.419	24239.419	.257	.62
Streets*Age*Experiment	1	5512.593	5512.593	.058	.81
Point Size	2	598685.833	299342.917	3.129	.05
Point Size * Experiment	2	1152951.193	576475.597	6.026	.0041
Point Size * Age	2	811439.706	405719.853	4.241	.02
Point Size*Age*Exp	2	107766.115	53883.057	.56	.57
Streets * Point Size	2	641665.724	320832.862	5.204	.0082
Streets*Point Size*Exp	2	10043.112	5021.556	.081	.92

Note: The actual ANOVA model used a full factorial of the within-subject main effects (number of streets and point size) fully crossed with each of the between-subject factors listed in the table above. Due to the length of this model, this ANOVA table has been abridged to include only the main effects and interactions which were expected to yield significant results. The remaining higher order interactions were calculated but not reported.

APPENDIX P - Comparison of Display Positions





Note: All measurements were taken from the steering wheel adjusted in mid-position.

APPENDIX Q - Simulator Validation Task 3 ANOVA Table

Source	df	Sum of Squares	Mean Square	F-Value	P-Value
Between Subject					
Age	1	1.856 E9	1.856 E9	52.820	<.001
Gender	1	64089565.440	64089565.440	1.838	.19
Age * Gender	1	1.372 E8	1.372 E8	3.963	.06
Experiment	1	1.189 E8	1.189 E8	3.411	.07
Experiment * Age	1	840034.250	840034.250	.024	.88
Subject(Group)	30	1.046 E9	3.487 E7	-	-
Within Subject					
Number of Streets	1	1.359 E9	1.359 E7	213.133	<.001
Streets * Experiment	1	15438298.582	15438298.582	2.420	.13
Streets * Age	1	64060043.201	64060043.201	10.044	.0035
Streets*Age*Exp	1	1255025.056	1255025.056	.197	.66
Point Size	2	36864171.317	1.843 E7	4.865	.01
Point Size * Experiment	2	80039972.858	4.002 E7	10.543	<.001
Point Size * Age	2	21416213.050	1.071 E7	2.821	.07
Point Size*Age*Exp	2	13071358.643	6535679.322	1.722	.19
Streets * Point Size	2	752027.884	376013.942	.116	.89
Streets*Point Size*Exp.	2	24294965.829	1.215 E7	3.736	.03
Streets*Point*Exp*Age	2	20275444.429	1.014 E7	3.118	.05
Location	3	1.071 E9	3.569 E8	68.483	<.001
Location * Experiment	3	14527141.257	4842380.419	.929	.43
Location * Age	3	60307872.903	2.010 E7	3.857	.01
Location*Age*Exp	3	14143807.447	4714602.482	.905	.44
Location * Streets	3	1.125 E8	3.751 E7	11.481	<.001
Location*Streets*Exp	3	23991077.764	7997025.921	2.448	.069

Note: The actual ANOVA model used a full factorial of the within-subject main effects (number of streets, point size, and location) fully crossed with each of the between-subject factors listed in the table above. Due to the length of this model, this ANOVA table has been abridged to include only the main effects and interactions which were expected to yield significant results. The remaining higher order interactions were calculated but not reported.